THE STRATIGRAPHY OF
THE AMURI LIMESTONE GROUP,
EAST MARLBOROUGH,
NEW ZEALAND.

A thesis
submitted in fulfilment
of the requirements for the Degree
of
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in the
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by

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with 5 separate maps in back pocket.

"I want to know how
God created this world.
I am not interested in
this or that
phenomenon, in the
spectrum of this or
that element; I want to
know his thoughts; the
rest are details."

ALBERT EINSTEIN

Princeton, 1946.

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ABSTRACT

An extensive study of the stratigraphy of the Amuri Limestone Group (Upper Cretaceous - Upper Eocene) and the enclosing units in East Marlborough has been undertaken. The study includes regional correlation of detailed measured sections in conjunction with lithofacies descriptions, micropaleontological age determinations, petrographic examination, and geochemical analysis. A revised New Zealand Paleogene time scale has been compiled to take into account recent major revisions of international Cenozoic geochronology.

The Amuri Limestone Group (c.660m maximum thickness) incorporates 6 Formations: Mead Hill Formation (mid Haumurian - lower Waipawan); Teredo Limestone (mid Waipawan - late Mangaorapan); Lower Limestone (mid Waipawan - mid Mangaorapan); Lower Marl (upper Waipawan - lower Heretaungan); Middle Limestone (lower Mangaorapan - lower Bortonian); Upper Marl (upper Porangan - upper Runangan). The Mead Hill Formation is diachronous and conformable on the Upper Iwitahi Group which includes the Woolshed Formation (lower - upper Haumurian) and the overlying Claverley Sandstone (upper Haumurian). The Mead Hill Formation contains the Flaxbourne Limestone Member (mid Haumurian) and Lower Chert Member (late Haumurian). The Lower Limestone contains the Upper Chert Member (mid Waipawan). The Fells Greensand Member (mid Bortonian) and Grass Seed Volcanics Member (upper Bortonian) are both intercalated within the Middle Limestone and Upper Marl.

With the exception of post-unconformity sandy facies, the Amuri Limestone consists of dcm-bedded, light greenish grey, well indurated, foraminiferal biomicritic calcilutites and poorly indurated, smectite-rich marls. Macrofossils are extremely rare. Cretaceous sequences are characterized by a poorly developed Planolites - Teichichnus ichnoassemblage; Paleogene facies are dominated by a Zoophycos -Planolites ichnoassemblage.

Pelagic limestone deposition was initiated within a central NW-trending trough and spread outwards onto the adjacent near-horizontal platform. Subsidence of the trough is inferred to have been maintained by reactivation of basement faults. Water depths on the platform are likely to have been relatively shallow (inner shelf) during the Late Cretaceous but much deeper (outer shelf - bathyal) during the Paleocene and Eocene. Basin morphology was the major control on lateral facies variations. Platform sediments are characteristically more thinly bedded, and the thickness of individual Formations is correspondingly attenuated, in comparison with trough facies. Chert and dolomite are restricted to the lower parts of the trough facies.

Basin-wide unconformities are recognized in the late Haumurian, mid Waipawan (sub-Teredo Limestone unconformity), mid Bortonian, and mid Whaingaroan. Although these breaks are disconformable in platform areas, they regionally account for large amounts of differential erosion. Submarine erosion, hardground formation, development of a Thallasinoides-dominated ichnofauna, glauconitization, phosphatization, and accumulation of a thin sandy facies are typical of unconformities outside the trough. Within the trough, the Haumurian and Waipawan breaks in deposition are represented by paraconformities or coevally deposited siliceous, pyritic mudstones.

The subfeldsarenitic Claverley Sandstone was intra-basinally derived from submarine erosion and reworking of the underlying Woolshed Formation. The detrital sand fraction of the Teredo Limestone was derived from reworking of the locally exhumed Claverley Sandstone, and from remobilization at depth and submarine extrusion of that unit. An extra-basinal source (possibly reworked quartzose coal measures) for the redeposited supermature quartzarenitic Fells Greensand is likely.

Pulses of (compressional?) tectonic activity immediately preceded and possibly continued during unconformity development. These tectonic events may provide an independent estimate of the timing of some of the major (Late Cretaceous - Cenozoic) plate tectonic events affecting the New Zealand region.

The amount of dextral movement on two of the major Marlborough Faults has been estimated from offsets in lithofacies and isopach patterns. 5-10km of transcurrent movement is recognized on the northern branch of the Hope Fault; 10-15km of right-lateral slip has occurred on the Kekerengu Fault.

Chapter One

INTRODUCTION

Location And Access

The study area (Figure 1.1), encompassing a NE-trending elongate strip of eastern Marlborough, covers an area of approximately $2800km^2$. The eastern and northern boundaries are delineated by the Pacific Ocean coast; the NW boundary is fixed by the Inland Kaikoura Range; the southern boundary is marked by the Conway River.

Major topographic features include the Seaward Kaikoura Range which reaches 2500m, and the Inland Kaikoura Range which reaches 2900m. The Clarence River flows NE along the valley between these two Ranges.

Access to many near-coastal outcrops can be gained on foot from public access routes. Clarence valley outcrops are only accessible via privately owned four wheel drive tracks which are commonly impassable.

Excellent exposure is provided by the numerous tributary stream sections and coastal outcrops.

Unless otherwise stated, grid references quoted in the text are from 1:63,360 (1inch to 1mile) NZMS1 Topographic Maps. Key localities appear in Figure 1.1.

Objectives

It became apparent in the early 1980's that a comprehensive study of the stratigraphy of the Amuri Limestone would be essential to a proper understanding of Cretaceous - Cenozoic geology of Marlborough.

The prime objective of this study is therefore to provide, in as much detail as possible, an account of the stratigraphic, paleotectonic, and paleoenvironmental setting of the Amuri Limestone in Marlborough. To accomplish this task, it is also necessary to take into account those units immediately above, below, and coeval with the Amuri Limestone. A major aim is to provide a systematic stratigraphic scheme which takes into account regional lithologic and chronostratigraphic variations.

In particular, the following poorly understood features and unresolved problems need to be addressed:

1. *The sequence of events and facies developments immediately preceding deposition of the Amuri Limestone.*

2. *The nature of the basal contact of the Amuri Limestone and its diachronous behaviour.*

3. *The nature of the upper contact and the lithologies which immediately overlie the Amuri Limestone.*

4. *The spatial distribution and age of the various lithologic units comprising the Amuri Limestone.*

5. *The lithologic nature of these units, including their structure, texture, composition (geochemical and petrographic), ichnology and paleontology.*

6. *The paleoenvironment of the Amuri Limestone with particular attention to paleobathymetry.*

7. *The relationship of the Amuri Limestone, at its time of deposition, to the plate tectonic setting of New Zealand.*

Although much of the previous work requires revision and correction, a large volume of existing data has been integrated into the study. This data includes paleontological age determinations, geologic maps, and stratigraphic descriptions derived from published sources, unpublished theses and reports, the New Zealand Fossil Record File, and personal communication.

Because the geochemistry of the chert and dolomite within the Amuri Limestone is the topic of a separate research project (M. Lawrence, in prep.) that aspect is not approached in this study.

Methods

Approximately 22 weeks of field work were carried out during the November - March periods of 1984-7. Work included tape-and-compass detailed stratigraphic logging; micropaleontological, petrographic, and geochemical sampling; structural logging; and paleomagnetic core drilling. Field numbers which are quoted in the text are indexed to official University Of Canterbury numbers in Appendix V.

Figure 1.1: Location and access map.

KEY
1. Ben More Stream
2. Blue Mountain Stream
3. Bluff River
4. Bluff Stream (lower)
5. Bluff Stream (upper)
6. Branch Stream
7. Chancet Rocks
8. Clinton Stream
9. Conway River (mouth)
10. Coverham
11. Cribb Creek
12. Dart Stream
13. Dead Horse Gully
14. Dee Stream
15. Deadman Stream
16. Deep Creek
17. Gentle Annie Stream
18. Grass Seed Stream
19. Isolation Creek
20. Jordan Stream
21. Limburn Stream
22. Limestone Hill
23. Marfell's Beach
24. Mead Stream
25. Monkey Face
26. Mt. Alexander
27. Muzzle Stream
28. Needles Point
29. Puhi Puhi River
30. Seymour Stream
31. Swale Stream
32. The Fell
33. Tirohanga Stream
34. Wallow Creek
35. Wharekiri Stream
36. Whisky Stream
37. Woodside Creek (lower gorge)
38. Woodside Creek (upper gorge)

Laboratory work has comprised:

1. Preparation and examination of approximately 250 representative thin sections.

2. XRD, XRF, and carbonate analyses of 75 representative samples.

3. Processing and picking of c.250 samples for foraminiferal extraction and identification.

4. Systematic search for previous age determinations listed in the New Zealand Fossil Record File (NZFRF).

5. Compilation and correlation of detailed measured sections.

The majority of microfossil age and paleoenvironmental determinations were made by C.P. Strong (New Zealand Geological Survey). Additional samples were examined by A.A. Cameron (University Of Canterbury) and G.J. Wilson (New Zealand Geological Survey). Macrofossil collections were examined by J.S. Crampton (New Zealand Geological Survey). All new age determinations have been lodged in the NZFRF and are listed in Appendix I.

Geologic Time Scale

A revised Paleogene time scale (Figure 1.2) was compiled for this study because various existing N.Z. time scales (e.g. Stevens 1981; Hoskins 1982; Nathan et al. 1986) were found to be inadequate and obsolete. The most recent of these scales fails to incorporate the recent major revisions of Cenozoic geochronology (Berggren et al. 1985a,b,c). Existing correlations (Hoskins 1982) between international and N.Z. plankton zones have been retained. The absolute age of boundaries and lengths of zones have been changed by recorrelating the NZ zones (and Stages) to the revised time scale of Berggren et al. (1985b). Considerable changes in the absolute length (m.y.) of many N.Z. Stages are evident (Table 1.1).

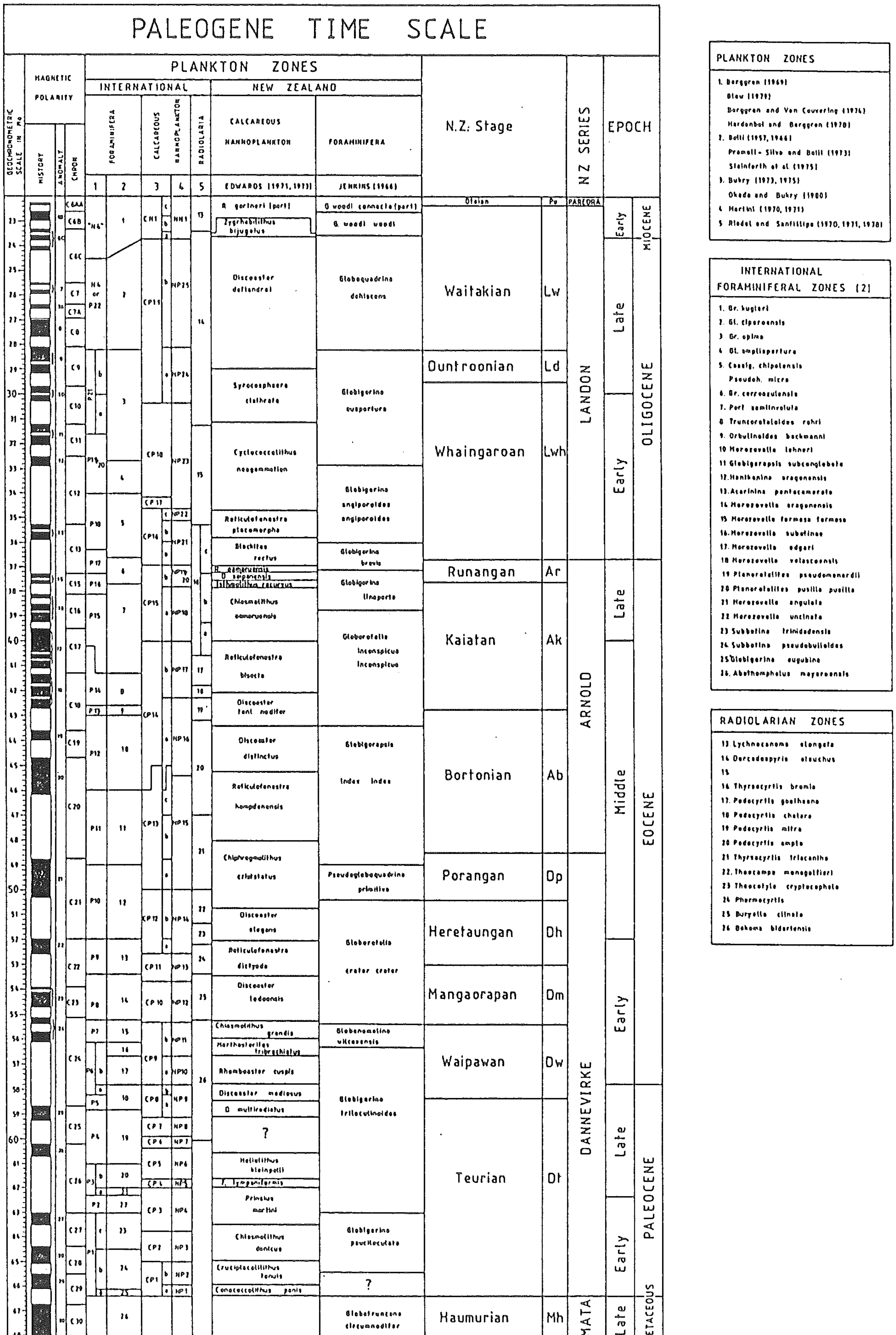


Figure 1.2: Revised Paleogene time scale (enlarged in back pocket)

Table 1.1. Comparison Of Revised Boundary Ages And Durations Of N.Z. Paleogene Stages With Stevens (1981).

This Study			Stevens (1981)	
Stage	Limits (Ma)	Duration (m.y.)	Limits (Ma)	Duration (m.y.)
Lw	28.2 - 22.4	5.8	26.5 - 24.0	c.2.5
Ld	29.5 - 28.2	1.3	28.0 - 26.5	1.5
Lwh	36.7 - 29.5	7.2	37.0 - 28.0	9.0
Ar	37.6 - 36.7	0.9	39.0 - 37.0	2.0
Ak	42.8 - 37.6	5.2	43.0 - 39.0	4.0
Ab	48.5 - 42.8	5.7	47.0 - 43.0	4.0
Dp	50.4 - 48.5	1.9	48.0 - 47.0	1.0
Dh	53.0 - 50.4	2.6	49.0 - 48.0	1.0
Dm	55.3 - 53.0	2.3	51.5 - 49.0	2.5
Dw	58.4 - 55.3	3.1	53.0 - 51.5	2.5
Dt	66.5 - 58.4	8.1	65.0 - 53.0	12.0

The most important differences between the Paleogene time scale presented here and the generally accepted time scale of Stevens (1981) are:

what are you trying to say?

1. The duration of the Eocene increases from c.15m.y. to c.21m.y. mainly at the expense of the Paleocene which decreases c.13m.y. to c.8m.y. The Eocene becomes the longest Cenozoic Epoch.

these are not defined in New Z.

2. The Teurian is condensed from c.12m.y. to c.8m.y.

3. The Teurian/Waipawan boundary shifts from 53.0Ma to 58.4Ma.

4. The Heretaungan expands from c.1m.y. to c.3m.y. and becomes longer than the Mangaorapan.

5. The Porangan doubles in length from c.1m.y. to c.2m.y.

6. The Bortonian expands from c.4m.y. to c.6m.y. and is longer than the Kaiatan.

7. The Runangan condenses from c.2m.y. to <1m.y. This shortening is due mainly to the adjustments made to length of the *Reticulofenestra oamaruensis*, *Discoas-*

ter saipanensis, and *Isthmolithus recurvus* NZ calcareous nannoplankton zones of Edwards (1971, 1973b).

8. The Whaingaroan condenses from c.9m.y. to c.7m.y.

9. The Waitakian expands from c.2m.y. to c.6m.y. and extends into the Miocene. ? it always has ?

Many of these adjustments help to explain some of the apparent anomalies in the stratigraphic record in Marlborough. A thin Teurian (and) sequence in many areas can be partly explained by the reduction in duration of that Stage. Previously unrecognized unconformities (which are detailed later in this study) bounding the Teurian in many parts of Marlborough further explain the attenuation. is consistent with the short length of the Age.

Similarly, the very thin Runangan sequence (where preserved) can readily be explained in terms of its reduced duration. Indeed, the preservation of any Runangan strata at all in Marlborough is probably very fortuitous in view of its truncation by a major erosional (mid Oligocene) unconformity.

Terminology And Definitions

Stratigraphic terminology and systematics follows the guidelines set down by Hedberg (1976). The ISSC (1987) has provided the following definitions of unconformities:

Unconformity:

A surface of erosion and/or nondeposition between rock bodies, representing a significant hiatus or gap in the stratigraphic succession caused by the interruption of deposition for a considerable span of time.

Angular Unconformity:

An unconformity in which the bedding planes below and above are at an angle to each other, denoting either tilting or folding before erosion and subsequent deposition or strong onlap.

Disconformity:

An unconformity in which the bedding planes below and above are essentially parallel, and across which erosion is evident.

Bates & Jackson (1980) provide the following definition:

Paraconformity:
An unconformity in which no erosion surface is discernible, and in which the beds above and below the break are parallel.

Textural and compositional carbonate classification and nomenclature follows Dunham (1962) and Folk (1959) respectively. Mixed siliciclastic/carbonate sandstone nomenclature follows Lewis (1984, Figure 93). *Marl* is accepted here to mean a clay mineral-rich calcilutite or calcareous mudstone which varies in composition between 35% and 85% $CaCO_3$ and is less indurated than interbedded clay mineral-poor calcilutites. Textural and compositional arenite classification follows Folk et al. (1970).

Toponomic classification of trace fossils follows Lewis (1984, Figure 34):

Table 1.2: Descriptive ichnologic terminology.

Character	Name
Trace occurs on top surface of stratum	epichnia or epirelief structure - concave groove or convex ridge
Trace occurs on bottom of stratum	hypichnia or hyporelief - convex ridge or concave groove
Trace is within stratum and infilled with similar sediment	endichnia
Trace is within stratum and filled with different sediment to that surrounding it	exichnia

Previous Work

This section is intended to provide a summary of the history of geological investigation in Marlborough, relevant to the Amuri Limestone. The important observations and conclusions are outlined in chronologic order.

1868 - 1890

The New Zealand Geological Survey (NZGS) carried out the early reconnaissance geology in Marlborough, and the majority of their accounts treat the Amuri Limestone only briefly. Their work was mainly descriptive and there was no attempt at stratigraphic correlation.

The first reference to the Amuri Limestone was by Buchanan (1868) (reviewed by Hector 1868) in his brief description of "*Crag Limestone*" near Ben More Stream. Haast (1871), who described the Amuri Limestone at Haumuri Bluff, as "*the Great limestone formation*", was the first to mention the conformable relationship with the underlying "*arenaceous limestones*" (Teredo Limestone). He also made reference to a "nodular greensand" overlying the Amuri Limestone.

As part of a regional geologic study, Hutton (1874) made the earliest reference to the name **Amuri Limestone**, presumably from a misspelling of Haumuri Bluff. Hector (1874), in a review of Hutton's work, made the first subdivision of the Amuri Limestone. He recognized that the upper contact at Kaikoura, is an unconformity overlain by a "*layer of brecciated fragments of calcareous greensands*". Hector (1874) included the Amuri Limestone within his "*Chalk Group*".

McKay (1877a) adopted Hector's subdivision with some refinements, and was the first to stratigraphically distinguish separate the chert beds (Mead Hill Formation) from the Amuri Limestone s.s.. He also recognized that the upper contact of the Amuri Limestone marks an important lithologic boundary and commented on the similarity of the Weka Pass Stone at Haumuri Bluff to its correlative in North Canterbury. Hector (1877) subsequently stated that there is no unconformity between the Amuri Limestone and the underlying or overlying units.

? what problem ?

Hutton (1885) published a study of the upper contact between the Amuri Limestone and the Weka Pass Stone but compounded the problem by apparently describing the contact between the Weka Pass Stone and the overlying Waima Siltstone.

A thorough review of the existing work was included by McKay (1885) in a major study of eastern Marlborough. This study included a summary of many previously undescribed sections, including important inland Clarence valley localities. He described the spatial distribution of the "flint beds", as well as volcanics at Kekerengu, that he concluded were coeval with the Amuri Limestone. His description of "*bands of hard calcareous greensandstone*" in Bluff River (probably what is now Bluff Stream) indicates his recognition of the Fells Greensand.

McKay (1890) made the first reference to the phosphatic nature of the nodules overlying the Amuri. This phosphatic nodular horizon was discussed by Morgan (1916), who provided detailed descriptions and geochemical analyses from several localities. He decided that the horizon represents a strong, widespread unconformity but could detect no discordance. Morgan also recognized the presence of two stratigraphically separate Amuri-type limestones at Flaxbourne River.

1916 - 1958

Very little investigation of the Amuri Limestone was carried out during this period. A better understanding of the principles of stratigraphy and a more detailed approach to field mapping is reflected in the work.

As part of a review of New Zealand Tertiary limestones, Marshall (1916) described the Amuri Limestone as a highly siliceous pelagic deposit which accumulated from the remains of marine organisms. He classed the Amuri Limestone as a pure *Globigerina* ooze that was probably deposited in water depths between 600 and 2500 fathoms.

An excellent description of the nature and distribution of the basal cherts was provided by Thomson (1916), who also made the first reference to the occurrence of dolomite. The summary lithostratigraphic description of the section in Mead Stream, forms the basis of the modern-day subdivision of the Amuri. He considered the Amuri Limestone to be largely a chemical deposit.

Speight & Wild (1918), who provided a detailed description of the upper contact of the Amuri Limestone, discussed its significance and decided that the sequence is conformable.

Thompson (1919) discussed the Amuri Limestone as part of the geology of the mid-Clarence and Ure River valleys. Although he described many sections in detail, paying special attention to the intercalated volcanics and basal chert, he made little attempt at correlation. He concluded that the base of the Amuri Limestone in the north must be much older than that in the south, and suggested that the upper surface is the same age between Mead Stream and Haumuri Bluff.

MacPherson (1952) produced a detailed geologic map of the Kekerengu area. He outlined the stratigraphy of the Amuri Limestone (presented earlier in MacPherson 1948), described the intercalated volcanics and "bentonites", and correlated parts of the Amuri Limestone with coeval North Island sequences.

Brief descriptions of the Amuri Limestone in the Puhi Puhi, lower- and mid-Clarence valleys were made by Jobberns (1932), King (1937) and Suggate (1958). Suggate considered the base of the Amuri Limestone to be unconformable on the Woolshed Formation. Although not supported with microfaunal evidence, he considered the "Flint Beds" in Bluff River to be a separate Formation. He briefly described the Grass Seed Volcanics and Cookson Volcanics at Limestone Hill, and described the upper contact of the Amuri Limestone in Seymour Stream as an unconformity.

What has m.e. got to do with sep/diff fm?

1962 - 1987

The main contribution to the existing knowledge of the Amuri Limestone were made during this era. Unpublished university theses resulted in the accumulation of a large body of valuable data. Many of these studies were initiated during, and intended to supplement, the NZGS reconnaissance (1:250,000) mapping project of the 1950's and 1960's. Later theses were able to more provide detailed studies of key areas and problems that were highlighted during the mapping programme. With few exceptions, interpretations were based on geosynclinal rather than plate tectonic concepts.

As part of the NZGS mapping project, Lensen (1962) produced the Kaikoura Sheet (16) which encompasses the bulk of Amuri Limestone exposures in Marlborough. Gregg's (1964) Hurunui Sheet (18) includes the remainder of the southern exposures covered by this study. The method of mapping employed in these sheets (i.e. using NZ Stages, rather than lithostratigraphic units), is unsuitable for the Amuri Limestone, primarily because of the diachronous stratigraphic contacts.

Hall (1964) divided the Amuri Limestone into seven Members in the Swale Gorge, in a subdivision very similar to that of Thomson (1916). He interprets the pure, hard limestones to be deep water *Globigerina* oozes, and the "bentonites" to have been deposited by turbidity currents.

An important study of Late Cretaceous foraminifera and stratigraphy was made by Webb (1966, 1971). This work involved the integration of measured sections with detailed microfaunal analyses. Detailed measured sections from key localities are included. One of his main conclusions is that the base of his *Globotruncana circumnodifer* Assemblage Zone coincides with the base of (his) Mead Hill Formation. He considers the top of the Mead Hill Formation to be an unconformity.

Armstrong (1972) examined the Amuri Limestone throughout coastal Marlborough and North Canterbury. He discussed its age and origin, but made no attempt at correlation. Special attention was given to the nature of the upper contact and the "chert problem". He recognized the biogenic origin of most of the Amuri Limestone, and that the main component is coccolithic debris.

A brief, accurate description of the distribution, stratigraphy, and sedimentology of the Amuri Limestone in the Ward area is provided by Price (1974).

Prebble (1976) followed Hall's stratigraphy for the Amuri Limestone in the Kekerengu - Ure River area. The age ranges and lithologic descriptions for the individual Members correspond closely to those of Hall.

The well exposed Cetaceous - Tertiary boundary within the Amuri Limestone at Woodside Creek was investigated and described by Strong (1977). Although a minor lithologic variation is recognized, the main emphasis is on the foraminiferal change across the boundary. Two further studies of the Cretaceous - Tertiary boundary were carried out by Strong (1984, 1985) at Chancet Rocks and Needles Point.

A bulletin dealing with the Piripauan and Haumurian stratotypes at Haumuri Bluff was compiled by Warren & Speden (1978). They described the units up to and including the basal contact of the Amuri Limestone. Extensive macrofossil collections were examined and these resulted in the erection of several biostratigraphic assemblage zonations.

In his study of the Cretaceous and Tertiary stratigraphy of the mid-Clarence valley, Reay (1980) provided a brief account of the stratigraphic position of the Amuri Limestone.

The seven Member stratigraphic subdivision of the Amuri Limestone was adopted by Osborne (1981) in his study of the Clarence - Kekerengu sector of Marlborough. Only brief descriptions of the units were given and biostratigraphic control relies largely on previous work.

The nature and origin of the smectite-rich mudstones (marls) within the Amuri Limestone was discussed by Fergusson (1985). Fergusson concluded that the marls were not derived from the degradation or alteration of in situ or transported volcanic ash, and that the term "bentonite" was inappropriate.

The results of the stratigraphic studies carried out as part of the NZ Geological Survey's Cretaceous - Cenozoic Project in North Canterbury are summarized in Browne & Field (1985). A brief summary of the distribution and gross stratigraphy of the Amuri Limestone is provided. Although these authors attempt to correlate several measured sections in southern Marlborough with those in Canterbury, little new data is added.

The significance of the elemental anomalies associated with the Cretaceous - Tertiary boundary at Woodside Creek have been investigated in several studies. Alvarez et al. (1980) cited Woodside Creek as one of three localities containing a boundary-layer with very high iridium concentrations. A more comprehensive study of the geochemistry of the boundary layer and the host rocks was made by Brooks et al. (1984). This work was supplemented by a study of the iron-rich microspheroids within the layer (Brooks et al. 1985), and by a summary of the geochemical variations across the boundary, with respect to several other NZ locations (Brooks et al. 1986).

The base of the Amuri Limestone in the Monkey Face area, was described by Crampton (1985), who concluded that the base is disconformable.

Several major research projects relevant to the Amuri Limestone in Marlborough, are being undertaken concurrently with this study. These projects include a study of the geochemistry of the chert and dolomite in the Amuri Limestone (M. Lawrence, in prep.), as well as compilation of data for the Marlborough and Canterbury sections of the NZ Geological Survey's Cretaceous - Cenozoic Project.

Geologic Setting

The geologic history of New Zealand records 3 main phases of sedimentation (Suggate et al. 1978):

1. Upper Precambrian to Devonian rocks that were deformed during the Tuhua Orogeny (Late Devonian - Early Carboniferous); these form the Tuhua Orogen.

2. Upper Carboniferous to Lower Cretaceous rocks that were deformed during the Rangitata Orogeny (Late Jurassic - Early Cretaceous); these form the Rangitata Orogen.

3. Upper Cretaceous and Cenozoic rocks were (and are still being) deformed by the Kaikoura Orogeny (Early Miocene - Present).

Sediments belonging to the Tuhua and Rangitata Orogens were deposited on, or were accreted to the margin of Gondwana (Bradshaw et al. 1980). Younger rocks provide a geologic record of New Zealand after its breakaway from that continent.

? this isn't true is it; what about the c. 10Ma change in pole of relative motion?

Plate Tectonic Setting

Only a relatively small proportion of the modern New Zealand continental landmass is exposed above present sea level. The major submerged elements include the Chatham Rise, Campbell Plateau, Lord Howe Rise, and the Norfolk Ridge (Figure 1.3). The sub-continent straddles an obliquely convergent section of the active plate margin between the Australian and Pacific Plates (Spörli 1980). The rates of relative movement between the Indian, Pacific, and Antarctic Plates ~~has been~~ have remained approximately ~~the same~~ constant since a major reorganization of plate geometry took place at Chron 18 (c.42 Ma) (Weissel et al. 1977).

The plate tectonic setting of New Zealand, immediately prior to deposition of the Amuri Limestone, is shown in Figure 1.4.1. At that time (Chron 32 c.73Ma), the Antarctic and Australian continents were

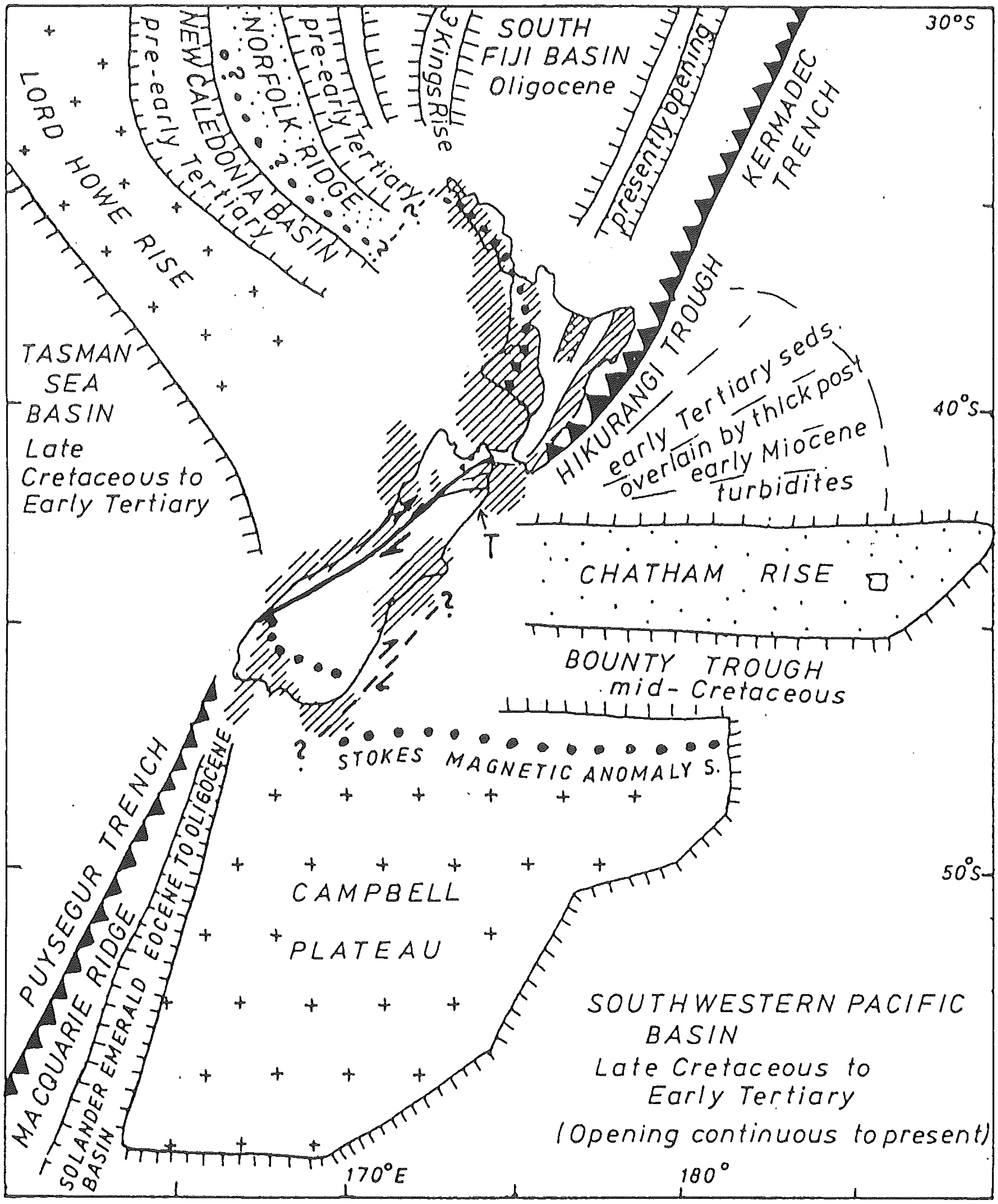


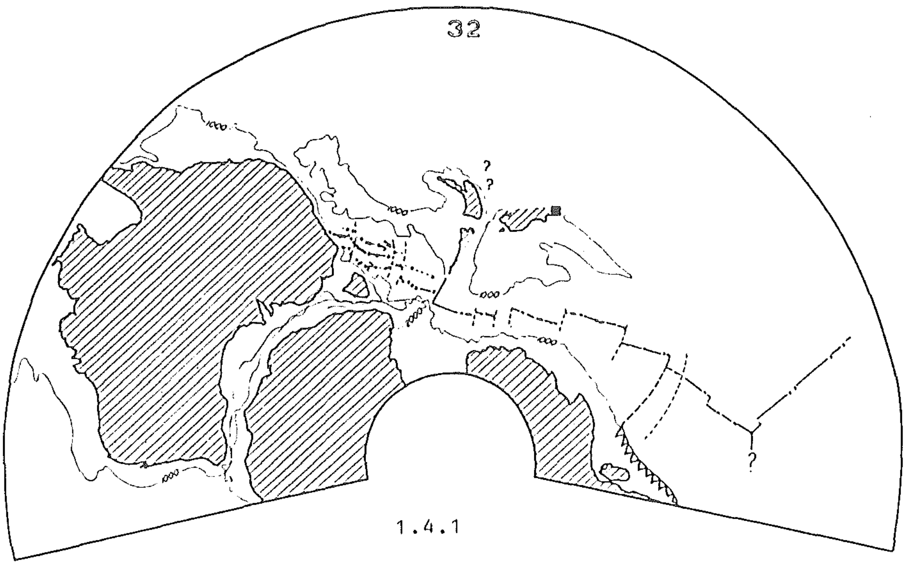
Figure 1.3: Major structural elements of the New Zealand continental block (after Sporli 1980). Crosses = Tuhua Orogen (Cambrian - Devonian). Dots = Rangitata Orogen (Permian - Cretaceous). Shaded = Major Upper Cretaceous - Cenozoic sedimentary basins. T = study area.

still joined together as part of Gondwana. A spreading ridge in the Tasman Sea, that was continuous with the Pacific - Antarctic Ridge, and which began propagating during Chron 34 (c.85Ma), had partially rifted the New Zealand subcontinent away from the main body of Gondwana. A failed rift system that was active in Late Cretaceous times, caused opening of the formerly aligned New Caledonia Basin and Bounty Trough, along a line parallel to, but oceanward of, the Tasman spreading ridge (Spörli 1980).

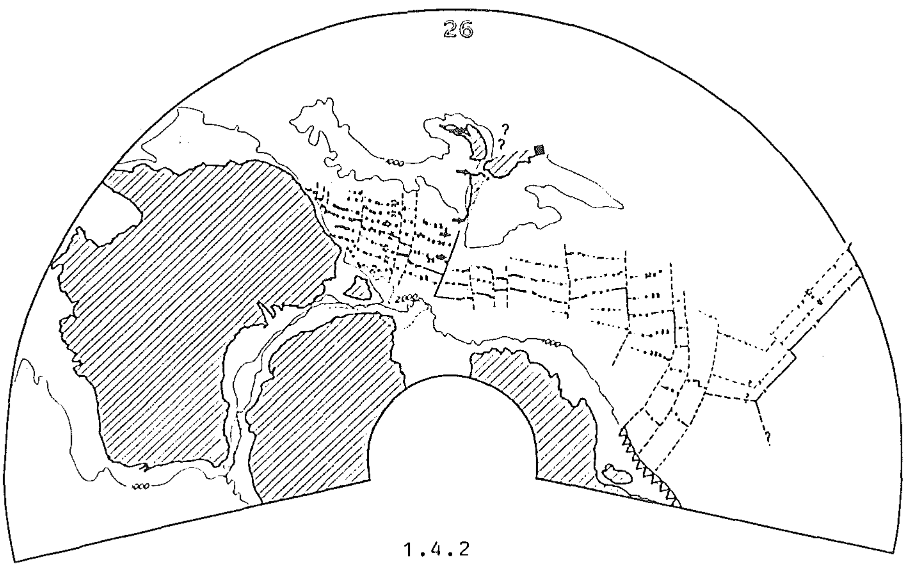
During Chron 32, eastern Marlborough occupied a position near to the leading edge of a passive continental margin. The nature of the transition between the continental and oceanic crust is uncertain, but there is no evidence that pre-Miocene subduction occurred at the boundary. Between Chrons 32 (c.73Ma) and 15 (c.37Ma) (i.e. the period of Amuri Limestone accumulation), eastern Marlborough, although experiencing continuous rotation, was always part of the stable continental margin and adjacent to an open ocean (Figures 1.4.1-3). The margin was continuous with the northern edge of the Chatham Rise to the east, and with the NE coast of the North Island and the Norfolk Ridge to the west (Ballance et al. 1982). The nearest region of contemporary major plate tectonic activity was active spreading along the Tasman - Pacific - Antarctic Ridge, almost 2000km SW.

Dextral strain through New Zealand was initiated by the cessation of spreading in the Tasman Sea during Chron 24 (c.56Ma), which effectively locked the Lord Howe Rise to the Australian Plate. Continued spreading along the Pacific - Antarctic Ridge caused anticlockwise rotation of the Chatham Rise - Campbell Plateau segment, with respect to the Lord Howe Rise. The initial strain accompanying the rotational stress was probably taken up within a broad zone either side of the present-day Alpine Fault (Walcott 1978).

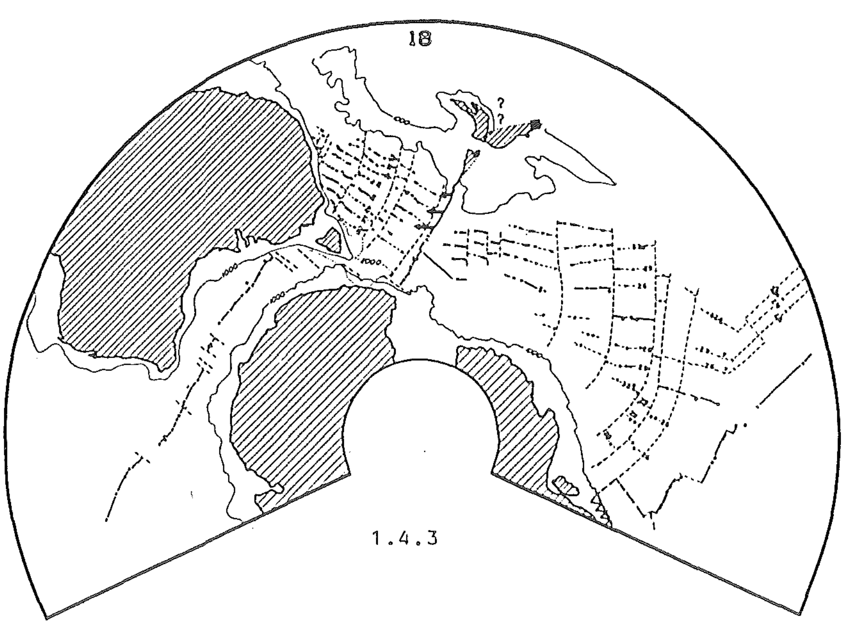
Rapid spreading along the SE Indian Rift between Australia and Antarctica, beginning at Chron 18 (c.43 Ma), propagated westwards and truncated the fossil Tasman Sea spreading system (Figure 1.4.3). According to Weissel et al. (1977), this spreading ridge eventually became continuous with the Pacific - Antarctic Ridge, along a series of major transform faults. Final separation of the South Tasman Rise segment of Australia from Antarctica in the mid Oligogene(?) led to the initiation of the Circum - Antarctic Current (Kennett et al. 1972, 1974).



1.4.1



1.4.2



1.4.3

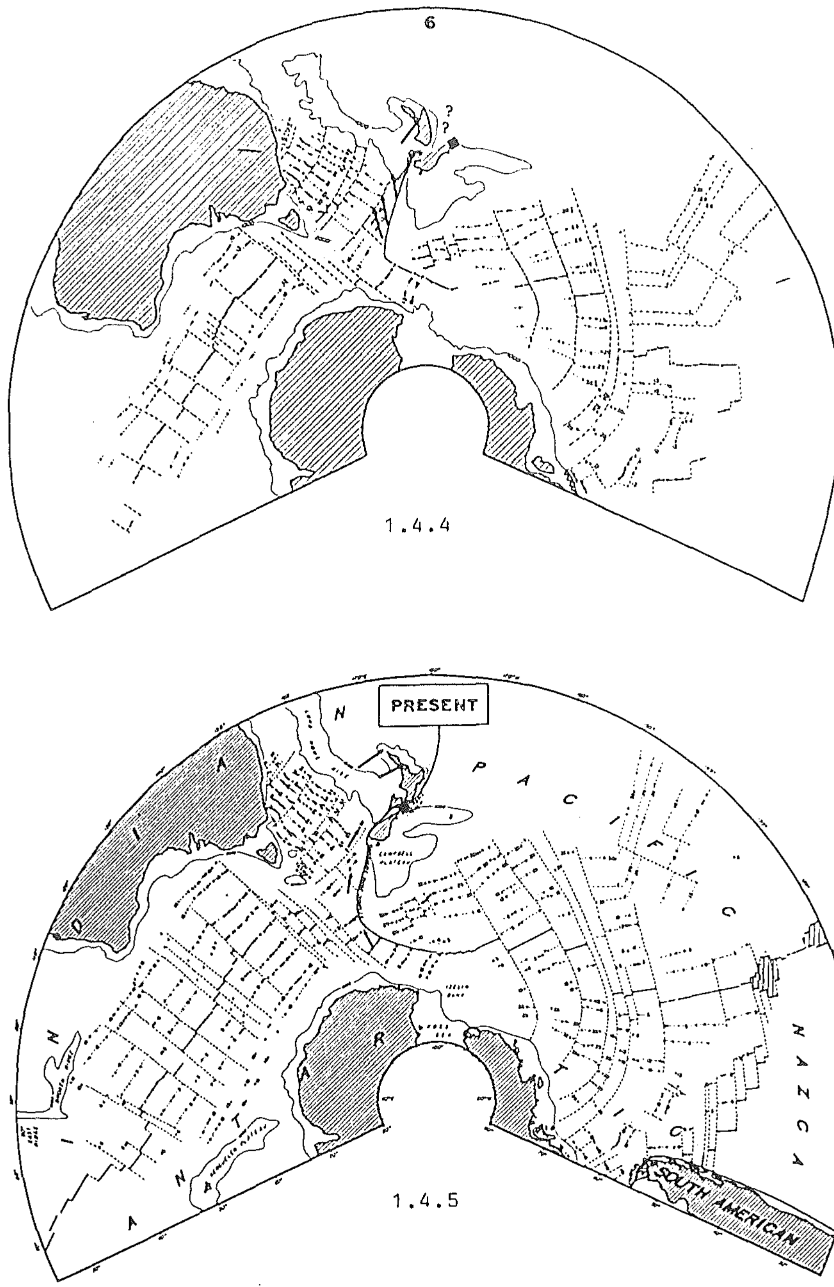


Figure 1.4: Paleotectonic reconstructions for the New Zealand - Australia - Antarctic region from Late Cretaceous to Present. Active plate boundaries indicated by solid lines. Magnetic anomalies indicated by dots and dashes (from Weissel et al. 1977). Study area shown by solid square.

.1: Chron 32 (c.73Ma)
.2: Chron 26 (c.62Ma)
.3: Chron 18 (c.43Ma)
.4: Chron 6 (c.23Ma)
.5: Present

As anticlockwise rotation of the Campbell Plateau - Chatham Rise segment continued during the Oligocene, a plate boundary became fully established along the Alpine Fault. Actual transcurrent displacement (c.480km) probably did not begin until latest Oligocene or earliest Miocene (Carter & Norris 1976; Walcott 1978). A west-dipping subduction zone beneath the Hikurangi Trough has probably existed since at least Early Miocene (van der Lingen & Pettinga 1980; Walcott 1984). The apron of Late Cretaceous and Cenozoic sediments that is inferred to have been deposited seaward of the Chatham Rise (Figure 1.3), has been scraped off the descending oceanic slab and accreted against eastern North Island as imbricate thrust wedges which form part of the East Coast Deformed Belt (Lewis 1980).

Since the Oligocene, rotation of the Pacific segment of New Zealand has continued but the finite pole of rotation for the Pacific - Australian Plate pair has moved steadily southward (Walcott 1978, 1984; Stock & Molnar 1982). This polar migration has caused the vector of plate convergence to steadily become more compressive across the Alpine Fault, leading to uplift of the Southern Alps and the Kaikoura Ranges. The vector of Pacific Plate motion relative to the plate boundary is sufficiently oblique in Marlborough, to cause dextral transcurrent movement along the Wairau, Awatere, Clarence, and Hope Faults, which are splays or continuations of the Alpine Fault (Freund 1971; Bibby 1976). The present day gross structural configuration of eastern Marlborough (Figure 1.5) reflects the mid/Miocene collision of the north-west tip of the Chatham Rise with the Australian segment of the New Zealand subcontinent. Evidence for the timing of the collision, which resulted in major uplift associated with the onset of the Kaikoura Orogeny, is provided by the age of the Great Marlborough Conglomerate (Prebble 1980).

Structural Setting

The study area lies at the southern end of the East Coast Deformed Belt (ECDB) as defined by Spörli (1980). The ECDB, which extends as far north as East Cape in the North Island, represents a NE-trending zone of Late Tertiary subduction-related deformation. The style and intensity of deformation varies and decreases in a SW direction. In the east coast of the North Island, where the ECDB is an active accretionary prism, thrust tectonics are dominant and large-scale gravity sliding is common. Much of the Upper Cretaceous - Cenozoic sequence in these areas is allocthonous with respect to the Mesozoic undermass (Pettinga 1982).

In contrast, basement deformation of the Marlborough sector is characterized by NE-trending transcurrent faulting. Large scale (c.10km), rapid (c.10mm/yr), vertical displacements are associated with the major strike-slip faults (Freund 1971). The change in tectonic style between the North and South Island is associated with the lateral transition from subducting to transform plate margin (Alpine Fault) (Walcott 1984).

The Upper Cretaceous - Cenozoic sedimentary cover throughout most of Marlborough, is essentially rooted to the Jurassic - Lower Cretaceous basement. Post-Oligocene deformation of the cover, which culminated in Plio-Pleistocene times, consisted (sequentially) of NW-directed thrusting, folding along NE-trending axes, and dextral faulting (Prebble 1980). Local basement/cover decollements resulted from early transcurrent displacement of the undermass, while the younger sedimentary sequence remained semi-contiguous (Prebble 1980).

Chapter Two

OUTLINE OF STRATIGRAPHY

2.1 Regional Stratigraphy

Introduction

Before attempting to discuss existing and proposed stratigraphic schemes for the Amuri Limestone, it is first necessary to outline in some detail the position which the unit occupies within the overall stratigraphy of Marlborough. In general, only those rocks in direct or close stratigraphic contact with the Amuri Limestone have been investigated in the field. Stratigraphy and facies interpretations of pre-Haumurian lithologic units are largely based on Lensen (1978a), but attempt to integrate subsequent work (Warren & Speden 1978; Reay 1980; Browne & Field 1985; Ritchie 1986).

Actual thicknesses of units are not discussed here but the general trends are shown in Figure 2.1.1. For the purposes of this section, only the mid Cretaceous to Lower Miocene rocks are differentiated. These units provide a record of sedimentation in the period between the close of the Rangitata Orogeny and the onset of the Kaikoura Orogeny (see Chapter 1).

Figures 2.1.1 & 2.1.2 are intended to illustrate litho- and chrono-stratigraphic relationships between the major Cretaceous and Tertiary units in eastern Marlborough. Figure 2.1.3 summarizes the stratigraphy at Group level.

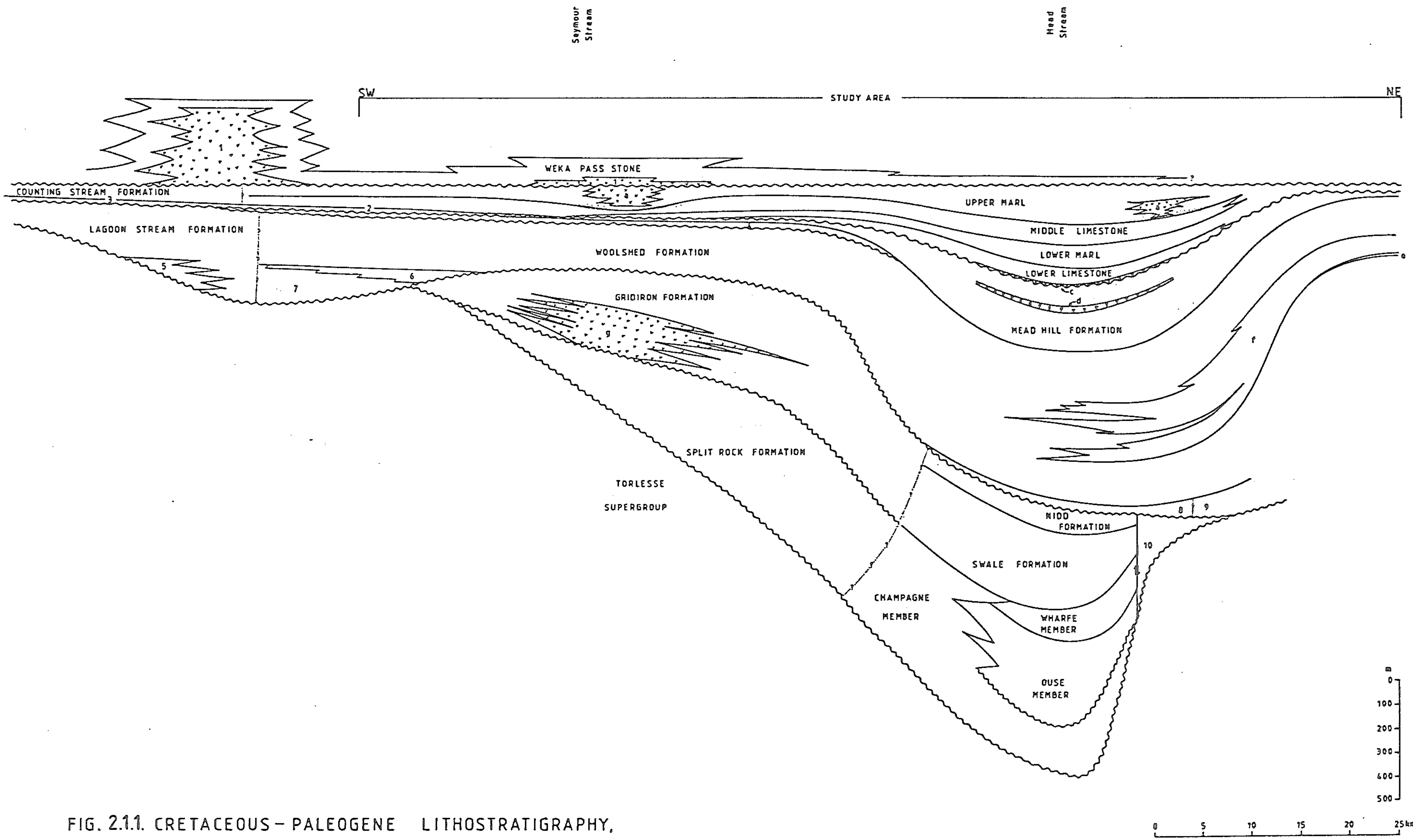


FIG. 2.1.1. CRETACEOUS – PALEOGENE LITHOSTRATIGRAPHY, EAST MARLBOROUGH, NEW ZEALAND.

(SEE FIG.2.1.2 FOR KEY)

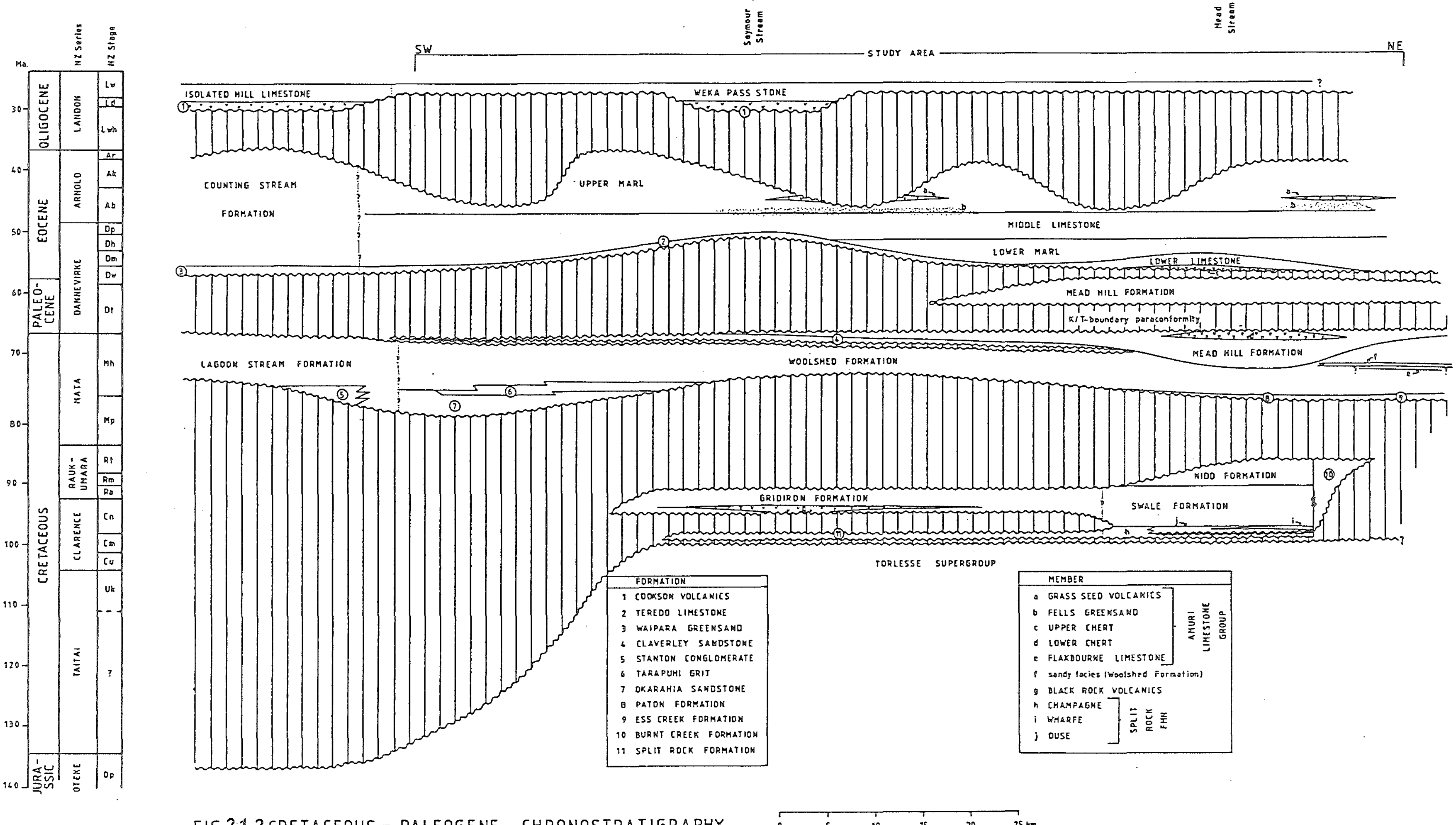


FIG.2.1.2.CRETACEOUS - PALEOGENE CHRONOSTRATIGRAPHY,
EAST MARLBOROUGH, NEW ZEALAND.

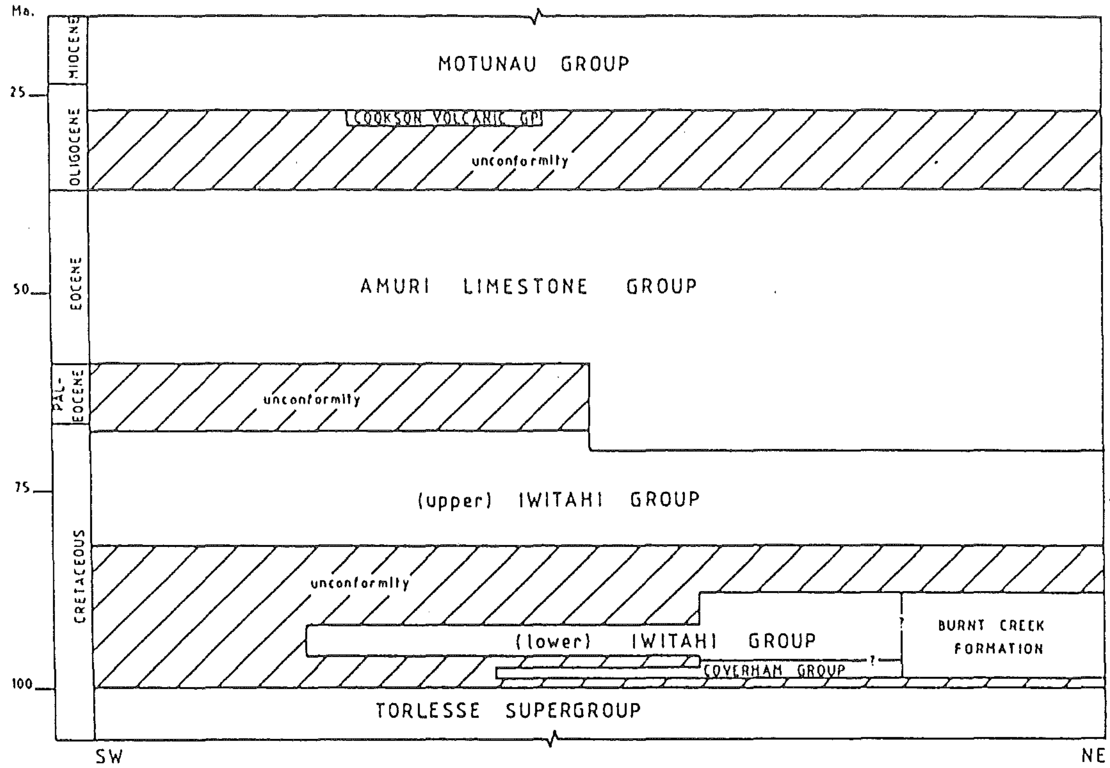


Figure 2.1.3: Generalized chronostratigraphic scheme for Marlborough.

this is a metamorphic zone

Torlesse Supergroup

The oldest suite of rocks in eastern Marlborough comprise the Torlesse Supergroup, and effectively constitute basement for the area. The Torlesse consists of unfossiliferous, very well indurated flysch-like sequences, massive greywacke sandstones, massive argillites, with minor conglomerates and volcanics (Lensen 1978a). The unit ranges in age from Jurassic in the south to mid-Cretaceous in the north.

Coverham Group

Summary

Formation	Age	Member	Facies
Split Rock Formation	Motuan	Wharfe Member	flysch
		Ouse Member	siltstone
		Champagne Member	flysch
		Cold Stream Siltstone Member	siltstone
		Bluff Dump Member	flysch
		Tentpoles Conglomerate Member	submarine debris flows
Burnt Creek Formation	Motuan - Teratan		allochthonous flysch

The Coverham Group consists of a basal conglomerate overlain by flysch-like sandstone and non-calcareous siltstones deposited in a deep water marine environment as part of a submarine fan complex (Reay 1980; Ritchie 1986).

According to Lensen (1978a), the Group includes all rocks of Motuan age which unconformably overlie Torlesse basement. His definition includes the Split Rock Formation, Ouse Siltstone, Wharfe Sandstone, together with the Swale Siltstone. Subsequent work (Reay 1980; Ritchie 1986) indicates that the latter three units, together with the Champagne, are best considered as Members of the Split Rock Formation.

Ritchie (1986) reinterprets the Burnt Creek Formation as part of the Coverham Group, but suggests that subsequent tectonism, prior to deposition of the overlying Paton Formation, has juxtaposed the unit against the coeval Split Rock Formation.

Facies relations suggest that the depositional patterns of the post-Torlesse Motuan sequence were at least partially controlled by contemporaneous growth faults (Laird & Lewis 1986; M. Laird, NZGS, pers. comm. 1987).

Iwitahi Group

Summary

Formation	Age	Member	Facies
Claverley Sandstone	Haumurian		shallow marine sandstone
Woolshed Formation	Haumurian	southern facies	shallow marine siltstone
		northern facies	deep marine zst & flysch
Tarapuhi Grit	Haumurian		shallow marine cgl
Okarahia Sandstone	Piripauan - Haumurian		shallow marine sandstone
Ess Creek Formation	Piripauan		marine siltstone
Paton Formation	Piripauan		glauconitic sandstone
Nidd Formation	Teratan		shallow marine sandstone
Gridiron Formation	Ngaterian - Arowhanan	Bluff Sandstone	shallow marine sandstone
		Black Rock Volcanics Member	subaerial basalts
		Warder Coal Measures	non-marine
Swale Formation	Ngaterian		marine siltstone

Previously defined by Lensen (1978a) and Browne & Field (1985) as those units resting unconformably on Motuan or older rocks; the Iwitahi Group includes shallow marine to non-marine sandstones, siltstones, mudstones, volcanics, conglomerates, and coal measures of Ngaterian to late Haumurian age.

The shallow water to non-marine deposits of the Gridiron Formation of central Marlborough grade laterally northwards into deeper water facies (Swale and Nidd Formations) near Coverham. These units are coeval with at least the upper part of the allochthonous Burnt Creek Formation (Ritchie 1986).

These lower units of the Iwitahi Group are separated from the overlying formations by a widespread hiatus. The depositional break is marked by a strong unconformity south of Coverham, and to the north, by a widespread glauconitic sandstone (Paton Formation). The succeeding units are nowhere older than Piripauan and range up to latest Haumurian in age. This upper sequence, which is dominated by the Woolshed Formation, and partly capped by the Claverley Sandstone, is described in detail in Chapter 3. The conformable sequence of Mata Series sediments (i.e. Okarahia Sandstone, Tarapuhi Grit, Woolshed Formation, Claverley Sandstone) at Haumuri Bluff are included within the Eyre Group by Browne & Field (1985). For reasons of their greater affinity and continuity with northern units, these Formations have been placed within the Iwitahi Group in this thesis.

From the preceding discussion, and from Figure 2.1.2, it is clear that the definition of the Iwitahi Group, in the sense of Lensen (1978a), is unpractical. On the basis of lithologic contrast and the existence of a major (lower?) Piripauan unconformity, it is more logical to separate out those non-calcareous Formations of Piripauan to Haumurian age which rest unconformably on Teratan and older rocks as being part of a distinct sequence.

Whether these younger units should be removed from the Iwitahi Group and included in a new group is beyond the scope of this study. The convention which is tentatively accepted here is that the Iwitahi Group be broken into Lower and Upper divisions. The Lower Iwitahi Group and the Coverham Group together form an unconformably bounded unit or synthem (ISSC 1987).

Amuri Limestone Group

The upper limit of the Iwitahi Group is set at the base of the Amuri Limestone Group. North of Bluff River, Amuri Limestone of late Haumurian age (Mead Hill Formation) conformably overlies the upper Iwitahi Group sediments. To the south, the base of the Amuri Limestone (Teredo Limestone Formation) is Early Eocene in age and rests unconformably on either Claverley Sandstone or Woolshed Formation.

Motunau Group and Cookson Volcanic Group

A regional angular unconformity or disconformity separates the Amuri Limestone Group from the overlying Cookson Volcanic Group (Oligocene) and limestones, sandstones and siltstones of the Motunau Group (Oligocene - Miocene). The Cookson Volcanics in Marlborough are restricted to the Limestone Hill - Seymour Stream area, where they are Whaingaroan in age and are overlain conformably by calcarenites (Weka Pass Stone) of Whaingaroan to Waitakian age.

Elsewhere in Marlborough, Weka Pass Stone of early Waitakian age rests directly on Amuri Limestone. Weka Pass Stone grades up into Waima Siltstone of Waitakian to younger age. Great Marlborough Conglomerate occurs as Early Miocene lenses within Waima Siltstone and incorporates clasts derived from Torlesse, Coverham, Iwitahi, Amuri, Cookson Groups, as well as from cannibalized Waima Siltstone (Lewis et al. 1980).

2.2 Existing Amuri Limestone Stratigraphy

One of the problems created by the large number of previous authors that have worked on the Amuri is that there has been a proliferation of an equally large number of stratigraphic schemes. These schemes are presented in chronologic order in Figure 2.2.1 beginning with Hector's (1871) crude subdivision and ending with those of Fergusson (1985) and Browne & Field (1985). The salient points of these schemes, which include the recognition, basis, and present status of genetic stratigraphic divisions are outlined below.

The first recognition of the Amuri Limestone as a distinctly different unit from the underlying beds was made by Hector (1868), when he separated the "Chalk Marls" from the underlying "Amuri Beds". On the basis of this classification, it is unfortunate that the name "Amuri Limestone" was later given to the overlying limestone (Hutton 1874), but nevertheless the name has been retained.

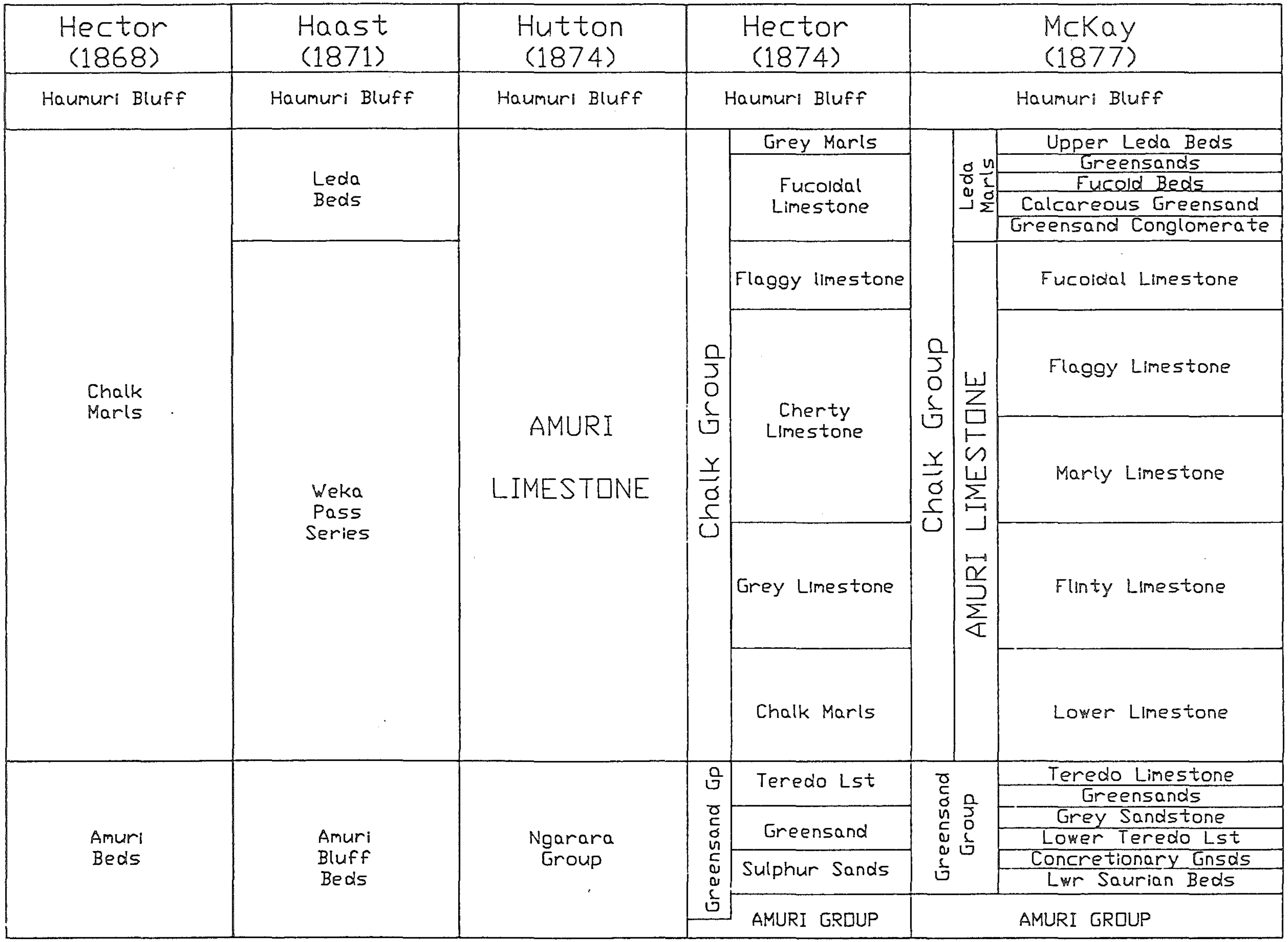
Little attempt was made to give the Amuri Limestone stratigraphic status prior to Armstrong (1972) who classified the unit as a Formation. Browne & Field (1985) realized that without a clearer understanding of the stratigraphy of the Amuri Limestone in Marlborough, it would be inappropriate to apply a formal definition. They classified the Amuri Limestone under the heading "Late Cretaceous - Mid Oligocene Limestone" sic with status pending further investigation; further south in Canterbury, they considered that the Amuri Limestone best fits into the stratigraphic hierarchy as a Formation.

The first internal subdivision of the Amuri Limestone was presented by Hector (1874), for the section at Haumuri Bluff. However, the sequence there is not fully representative of the Amuri Limestone throughout the rest of Marlborough. Morgan (1916) summarized the internal stratigraphy of the Amuri Limestone at Mead Stream, where the unit reaches its greatest thickness. Apart from adjustments to his nomenclature and estimates of thickness, the six-fold subdivision he recognized then is the same as that in current usage. The terminology was changed, age constraints were introduced, and member status was given to each unit by Hall (1964), who also introduced the Fells Greensand as a Member.

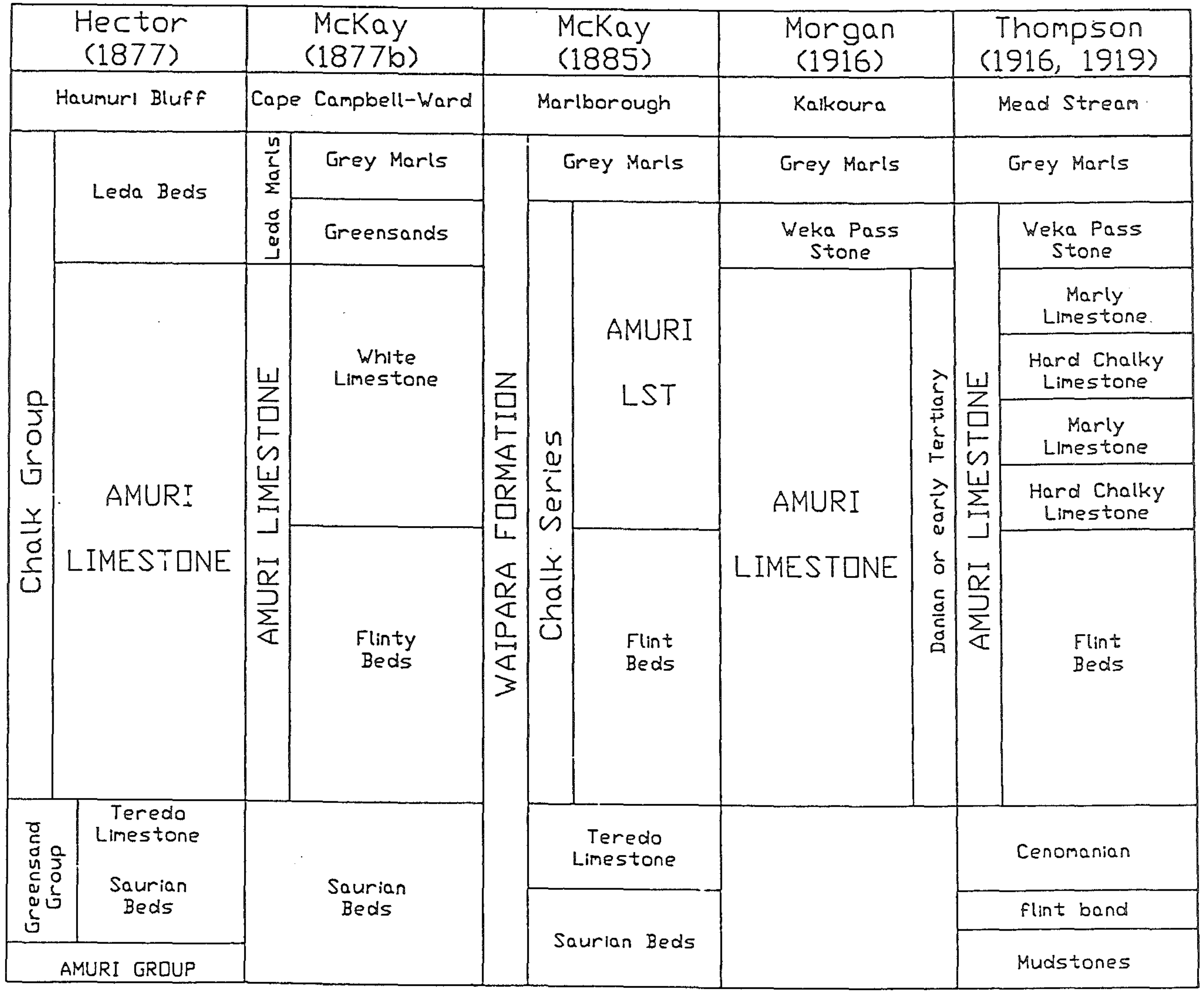
Important subsequent additions and refinements were made to Hall's

Figure 2.2.1: History of development of Amuri Limestone stratigraphy and nomenclature.

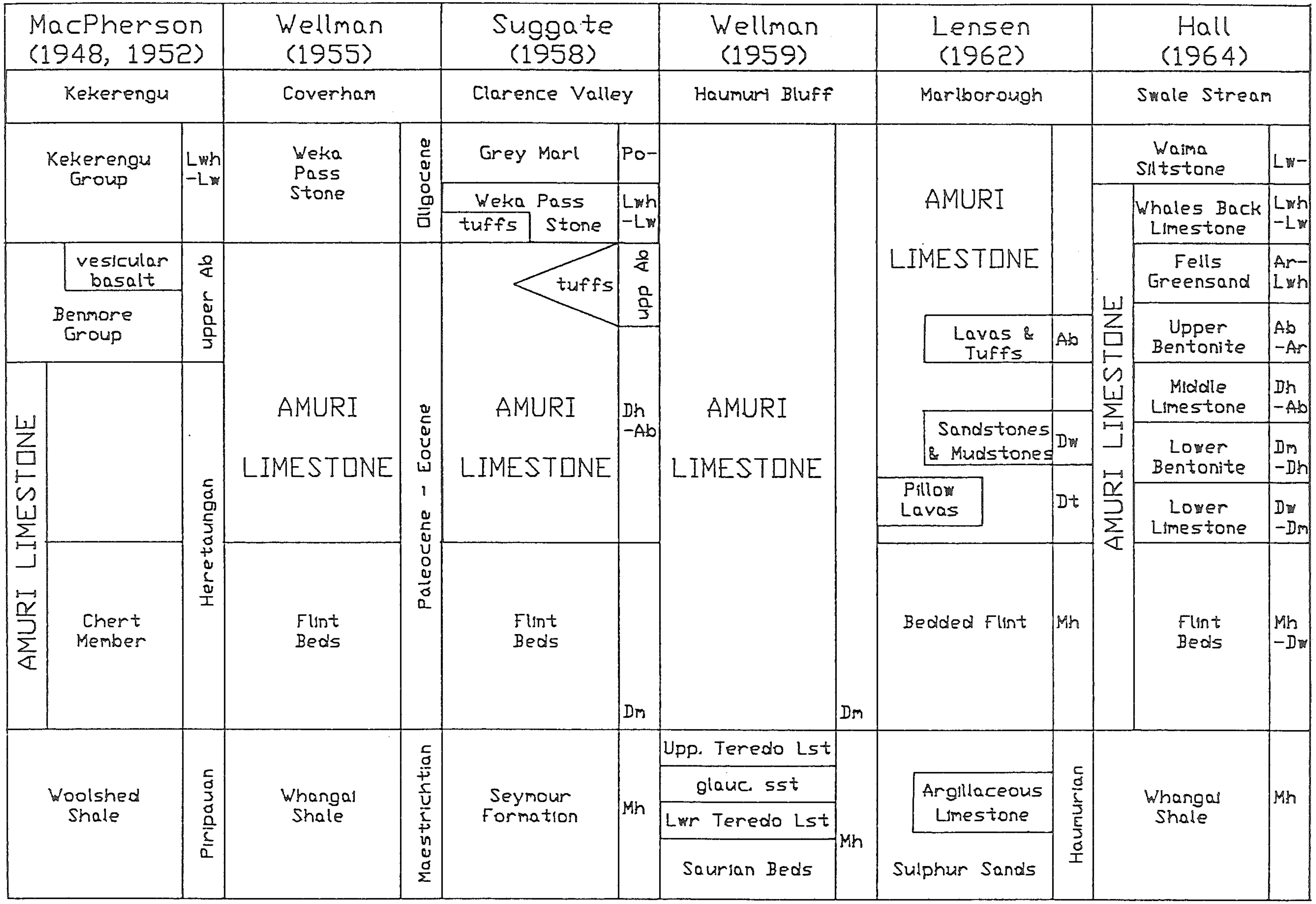
2.2.1a



Hector (1868)
Haast (1871)
Hutton (1874)
Hector (1874)
McKay (1877)
Haumuri Bluff
Haumuri Bluff
Haumuri Bluff
Haumuri Bluff
Haumuri Bluff
Chalk Marls
Amuri Beds
Leda Beds
Weka Pass Series
Amuri Bluff Beds
AMURI LIMESTONE
Ngarara Group
Chalk Group
Grey Marls
Fucoidal Limestone
Flaggy limestone
Cherty Limestone
Grey Limestone
Chalk Marls
Greensand Gp
Teredo Lst
Greensand
Sulphur Sands
AMURI GROUP
Chalk Group
Leda Marls
AMURI LIMESTONE
Upper Leda Beds
Greensands
Fucoid Beds
Calcareous Greensand
Greensand Conglomerate
Fucoidal Limestone
Flaggy Limestone
Marly Limestone
Flinty Limestone
Lower Limestone
Greensand Group
Teredo Limestone
Greensands
Grey Sandstone
Lower Teredo Lst
Concretionary Gnsds
Lwr Saurian Beds
AMURI GROUP

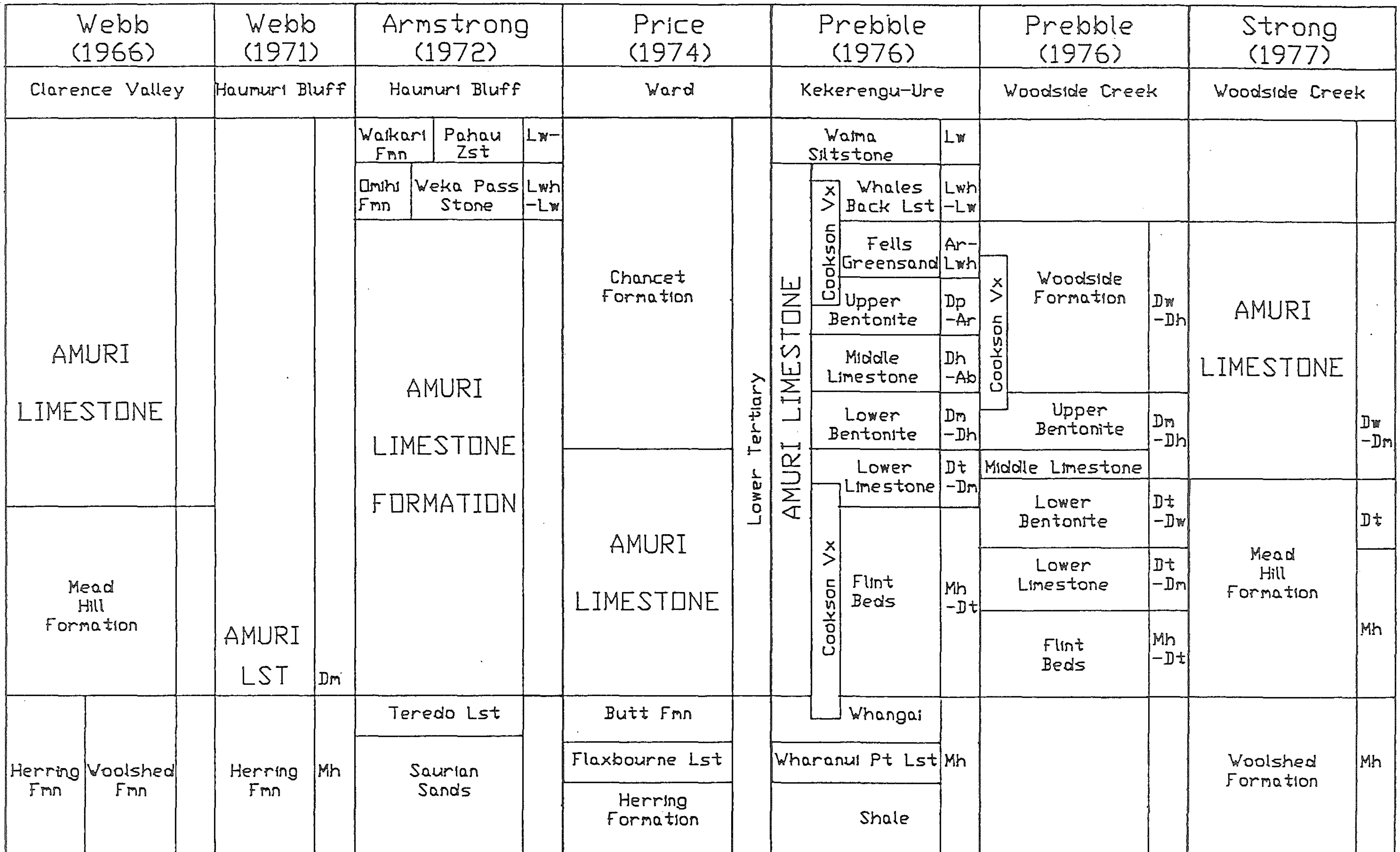

Hector (1877)
McKay (1877b)
McKay (1885)
Morgan (1916)
Thompson (1916, 1919)
Haumuri Bluff
Cape Campbell-Ward
Marlborough
Kaikoura
Mead Stream
Chalk Group
Leda Beds
AMURI LIMESTONE
Greensand Group
Teredo Limestone
Saurian Beds
AMURI GROUP
Leda Marls
Grey Marls
Greensands
AMURI LIMESTONE
White Limestone
Flinty Beds
Saurian Beds
WAIPARA FORMATION
Grey Marls
Chalk Series
AMURI LST
Flint Beds
Teredo Limestone
Saurian Beds
Grey Marls
Weka Pass Stone
AMURI LIMESTONE
Danian or early Tertiary
Grey Marls
AMURI LIMESTONE
Weka Pass Stone
Marly Limestone
Hard Chalky Limestone
Marly Limestone
Hard Chalky Limestone
Flint Beds
Cenomanian
flint band
Mudstones

2.2.1b


MacPherson (1948, 1952)
Wellman (1955)
Suggate (1958)
Wellman (1959)
Lensen (1962)
Hall (1964)
Kekerengu
Coverham
Clarence Valley
Haumuri Bluff
Marlborough
Swale Stream
Kekerengu Group
Lwh -Lw
vesicular basalt
Benmore Group
upper Ab
AMURI LIMESTONE
Heretaungan
Chert Member
Woolshed Shale
Piripauan
Weka Pass Stone
AMURI LIMESTONE
Flint Beds
Whangai Shale
Oligocene
Paleocene - Eocene
Maestrichtian
Grey Marl
Po-
Weka Pass
tuffs
Stone
Lwh -Lw
tuffs
upp Ab
AMURI LIMESTONE
Dh -Ab
Flint Beds
Dm
Seymour Formation
Mh
AMURI LIMESTONE
Dm
Upp. Teredo Lst
glauc. sst
Lwr Teredo Lst
Saurian Beds
Mh
AMURI LIMESTONE
Lavas & Tuffs
Ab
Sandstones & Mudstones
Dw
Pillow Lavas
Dt
Bedded Flint
Mh
Argillaceous Limestone
Sulphur Sands
Haumurian
Waima Siltstone
Lw-
Whales Back Limestone
Lwh -Lw
Fells Greensand
Ar- Lwh
Upper Bentonite
Ab -Ar
Middle Limestone
Dh -Ab
Lower Bentonite
Dm -Dh
Lower Limestone
Dw -Dm
AMURI LIMESTONE
Flint Beds
Mh -Dw
Whangai Shale
Mh

2.2.1c

2.2.1d


Webb (1966)
Clarence Valley
AMURI LIMESTONE
Mead Hill Formation
Herring Fmn
Woolshed Fmn
Webb (1971)
Haumuri Bluff
AMURI LST
Dm
Herring Fmn
Mh
Armstrong (1972)
Haumuri Bluff
Waikari Fmn
Pahau Zst
Lw-
Omihi Fmn
Weka Pass Stone
Lwh -Lw
AMURI LIMESTONE FORMATION
Teredo Lst
Saurian Sands
Price (1974)
Ward
Chancet Formation
AMURI LIMESTONE
Lower Tertiary
Butt Fmn
Flaxbourne Lst
Herring Formation
Prebble (1976)
Kekerengu-Ure
AMURI LIMESTONE
Waima Siltstone
Lw
Cookson Vx
Whales Back Lst
Lwh -Lw
Fells Greensand
Ar- Lwh
Upper Bentonite
Dp -Ar
Middle Limestone
Dh -Ab
Lower Bentonite
Dm -Dh
Lower Limestone
Dt -Dm
Cookson Vx
Flint Beds
Mh -Dt
Whangai
Wharanui Pt Lst
Mh
Shale
Prebble (1976)
Woodside Creek
Cookson Vx
Woodside Formation
Dw -Dh
Upper Bentonite
Dm -Dh
Middle Limestone
Lower Bentonite
Dt -Dw
Lower Limestone
Dt -Dm
Flint Beds
Mh -Dt
Strong (1977)
Woodside Creek
AMURI LIMESTONE
Dw -Dm
Mead Hill Formation
Dt
Mh
Woolshed Formation
Mh

2.2.1e

Suggate et al (1978)		Warren & Speden (1978)		Reay (1980)		Osborne (1981)		Browne & Field (1985)		Fergusson (1985)	
Marlborough		Haumuri Bluff		Mid-Clarence Valley		Clarence-Kekerengu		Nth Canterbury		Marlborough	
Grey Marl (Lw-); Kekerengu Formation	Oligocene	Walkari Formation	Sl-	Grey Marl	Po	Coastal Marlborough Fmn	Po-	MOTUNAU GROUP: Waima Formation	Lw-	Waima Siltstone	Lw
Weka Pass Stone (Lwh -Lw); Kekerengu Formation	Oligocene	Omihi Formation	L-S	Omihi Fmn: Weka Pass; Cookson Vx	Lwh -Lw	AMURI LIMESTONE: Top Limestone	Lwh -Lw	MOTUNAU GROUP: Spy Glass Formation	Ld -Po	AMURI LIMESTONE: Whales Back Limestone	Lwh -Lw
Benmore Bentonitic Shale & Cookson Volcanics	upper Ab	AMURI LIMESTONE	Ar	Grasseed Volcanics	Ak	Glauconitic Limestone	Ar-Lwh	AMURI LIMESTONE	Late Cretaceous - Mid Oligocene	Fells Greensand	Ar-Lwh
AMURI LIMESTONE	Ab	AMURI LIMESTONE		AMURI LIMESTONE		Upper Bentonite	Ab -Ar	AMURI LIMESTONE		Upper Marl	Dp -Ar
AMURI LIMESTONE		AMURI LIMESTONE		AMURI LIMESTONE		Middle Limestone	Dh -Ab	AMURI LIMESTONE		Middle Limestone	Dh -Ab
AMURI LIMESTONE		AMURI LIMESTONE		AMURI LIMESTONE		Lower Bentonite	Dm -Dh	AMURI LIMESTONE		Lower Marl	Dw -Dh
AMURI LIMESTONE		AMURI LIMESTONE		AMURI LIMESTONE		Lower Limestone	Dw -Dm	AMURI LIMESTONE		Lower Limestone	Dw
AMURI LIMESTONE (Dh)	Dw	AMURI LIMESTONE	Dm	AMURI LIMESTONE	Dh	Flint Beds	Mh -Dw	AMURI LIMESTONE		Flint Beds	Mh -Dt
Mh Herring Fmn; Mead Hill Flint	Dt	Teredo Lst Member	Dw	Dip Basin Greensand	Mh -Dw			EYRE GROUP: Teredo Lst; Claverley Formation	Mh -Dw	Whangai Shale	
Woolshed Fmn; Butt Fmn; Mirza Fmn	Mh	Claverley Sandstone	Mh	Herring Formation	Mh			EYRE GROUP: Claverley Formation		Whangai Shale	
Woolshed Fmn; Mirza Fmn	Mh	Conway Siltstone	Mh	Herring Formation	Mh			EYRE GROUP: Conway Formation	Mh -Dt	Whangai Shale	

scheme by Webb (1966) who coined the name Mead Hill Formation to replace "Flint Beds", and Prebble (1976) who introduced the Woodside Formation. The most recent refinement was by Fergusson (1985) who changed the two "Bentonite" Members to Lower and Upper Marl.

2.3 Proposed Amuri Limestone Stratigraphy

The Amuri Limestone divides into lithostratigraphic units that are mappable at a scale of 1:20,000 or larger which can be traced for distances in excess of 50km. Thicknesses of each unit are variable but are in the order of 100m at their maximum. Following Hedberg (1976), the most suitable status for such units is as Formations.

On this basis, each of the previously recognized units comprising the Amuri Limestone (i.e. Flint Beds, Lower Limestone, Lower Marl, Middle Limestone and Upper Marl) are upgraded in status from Members to Formations. While recognizing the problem of lithologic connotations in the existing Formation names, the nomenclature has been retained to reduce confusion. Substitution of existing names with geographically-derived replacements would be preferred if Hall's (1964) original nomenclature had not become entrenched. The name Mead Hill Formation is reinstated to replace "Flint Beds". The Teredo Limestone, which has never been included as part of the Amuri Limestone prior to this study and is generally much thinner than the other units, is also raised to Formation status.

The Fells Greensand and Grass Seed Volcanics are Members within the Middle Limestone and Upper Marl Formations. Two new units, which are introduced within the Mead Hill Formation and Lower Limestone respectively are named the Lower and Upper Chert Members. These Members may require redefinition following more detailed investigation (M. Lawrence, in prep.). The Flaxbourne Limestone Member is considered to be a part of the Amuri Limestone, because of its close lithologic affinity and probable lateral continuity with the base of the Mead Hill Formation.

— or Subgroup

Hedberg (1976, p34) suggests that "*a sequence of two or more contiguous formations with significant unifying lithologic features in common*" should constitute a group. In Marlborough, the Amuri Limestone fits this description and is consequently raised from Formation to Group status. The Amuri Limestone Group, is defined as all those units from the top of the upper Iwitahi Group up to the base of the Motunau or

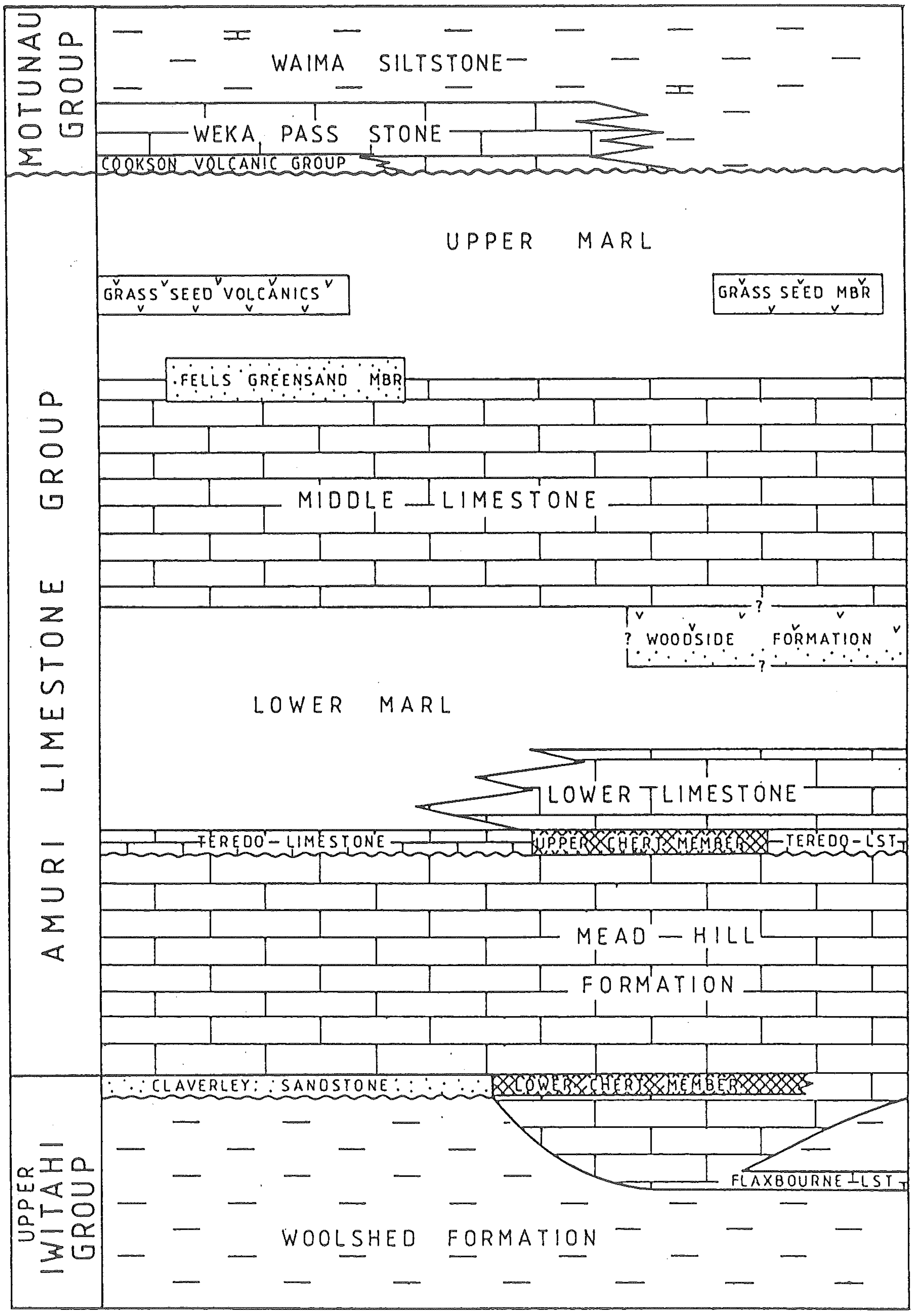


Figure 2.3: Summary stratigraphy of the Amuri Limestone in Marlborough.

Cookson Volcanic Groups (Figure 2.1.3).

The Amuri Limestone was never officially given a type section until Browne & Field (1985) formalized the section at Haumuri Bluff. Their holostratotype is "*from the top of the Claverley Sandstone (Teredo Limestone Member) at 032/523502 to the glauconitic, phosphatized pebble band at 032/525500, Haumuri Bluff*".

The only reasoning that they provide in support of their selection of this locality is that the section was accepted as the stratotype by previous workers. The designated section at Haumuri Bluff has the advantage that it has continuous exposure from bottom to top of the Amuri Limestone. These authors do not include any form of description as part of their type section definition.

The choice of Haumuri Bluff as type section is unfortunate, because the Amuri Limestone at that locality is atypical of the bulk of the unit throughout Marlborough. Hedberg (1976, p34) suggests that the type section of a group should be the type sections of its component formations. The section which best represents the expression of the Amuri Limestone Group, and also contains the type sections of all but one of the component Formations, is at Mead Stream. At this location, the Group is c.660m thick and extends from the faulted base of the Mead Hill Formation at S35/087450 up to the unconformable contact of the Upper Marl Formation with the overlying Weka Pass Stone at S35/076450.

A stratigraphic scheme most suitable for the Amuri Limestone in Marlborough is presented in Figure 2.3. This scheme is based primarily on the reference section at Mead Stream (Appendix IV: JM 30), but is modified to include units and relationships that are not necessarily best developed at that locality.

Not clear what you're doing here. You can't change a designated type loc., so I take it you are adding a standard reference section, in which case you should say so.

Chapter Three

PRE-AMURI LIMESTONE STRATIGRAPHY

Upper Iwitahi Group

The Upper Iwitahi Group in Marlborough is defined here to include all those Formations of Piripauan to Haumurian age that underlie the Amuri Limestone Group (see Chapter 2). The purpose of this section is to outline the facies development preceding the Amuri Limestone. Therefore, only those units that are in direct or near stratigraphic contact with the base of the Amuri Limestone are discussed in any detail. The relationship of the Upper Iwitahi Group to the Amuri Limestone Group is illustrated in Figures 2.1.1 & 2.1.2.

3.1 Woolshed Formation

Introduction

Although separated by an unconformity from the Amuri Limestone Group in southern Marlborough, the Woolshed Formation is coeval with, and conformable below, that unit in areas further north. *Conway*, *Herring*, *Woolshed*, *Mirza*, and *Butt* are the currently accepted Formation names used to describe what is considered here to be a single, laterally continuous unit. The lateral lithofacies variations of this unit are insufficient to justify its separation into individual formations.

Name, Definition And Synonomy

Woolshed Formation:	Branch Stream - Woodside Creek
Thomson (1916, 1919):	"Cenomanian mudstones"
MacPherson (1948, 1952):	"Woolshed Shale Group"
Wellman (1955, 1959):	"Whangai Shale"
Hall (1964):	" "
Prebble (1976):	" "

Herring Formation:	Seymour Stream - Branch Stream
Suggate (1958):	part of "Seymour Formation"
Webb (1966):	"dark sulphurous siltstones and sandstones"
Reay (1980):	"Herring Formation"

Conway Siltstone:	Kaikoura - Conway River
Warren & Speden (1978):	"dark grey massive jarositic siltstone with scattered spherical concretions"
Webb (1966):	"Herring Formation"
Hector (1874):	"Sulphur mudstones" or "sulphur sands"
Wellman (1959):	"Saurian Beds"
Browne & Field (1985):	"Conway Formation"

Butt Formation:	Needles Point - Chancet Rocks
Webb (1966):	"Woolshed Formation"
Webb (1971):	"Butt Formation"
Price (1974):	"alternating bands of sandstone and siltstone with some larger massive sandstone beds"

Mirza Formation:	Needles Point - Chancet Rocks
Webb (1966):	"Woolshed Formation"
Webb (1971):	"Mirza Formation"
Price (1974):	"a slightly silty, highly siliceous mudstone and shale"

The distribution of these 5 units, although lateral correlatives and lithologically indistinguishable, has been geographically restricted. The areal constraints appear to have been based on the geographic limits of previous workers' study areas rather than on geological factors.

It is proposed here that the separate Formation names listed above be abandoned in favour of a single unifying name rather than placing them into a new Group. If a new Formation name is adopted to replace the five existing names, additional confusion is inevitable. The name Woolshed Formation is retained at the expense of the others because it is the earliest published, and the area in which that unit was originally defined contains the thickest development of the unit.

The name Woolshed Formation was taken from "Woolshed Shale" by Webb (1966), to describe "*non-calcareous, dark argillaceous and micaceous siltstone*" containing "*thin bands of sandstone*", outcropping in Ben More Stream. At this location, Webb altered MacPherson's (1952) original definition to include dark siltstones between the underlying unnamed glauconitic sandstones (Paton Formation) and "*interbedded greensand and chert of the overlying Mead Hill Formation*".

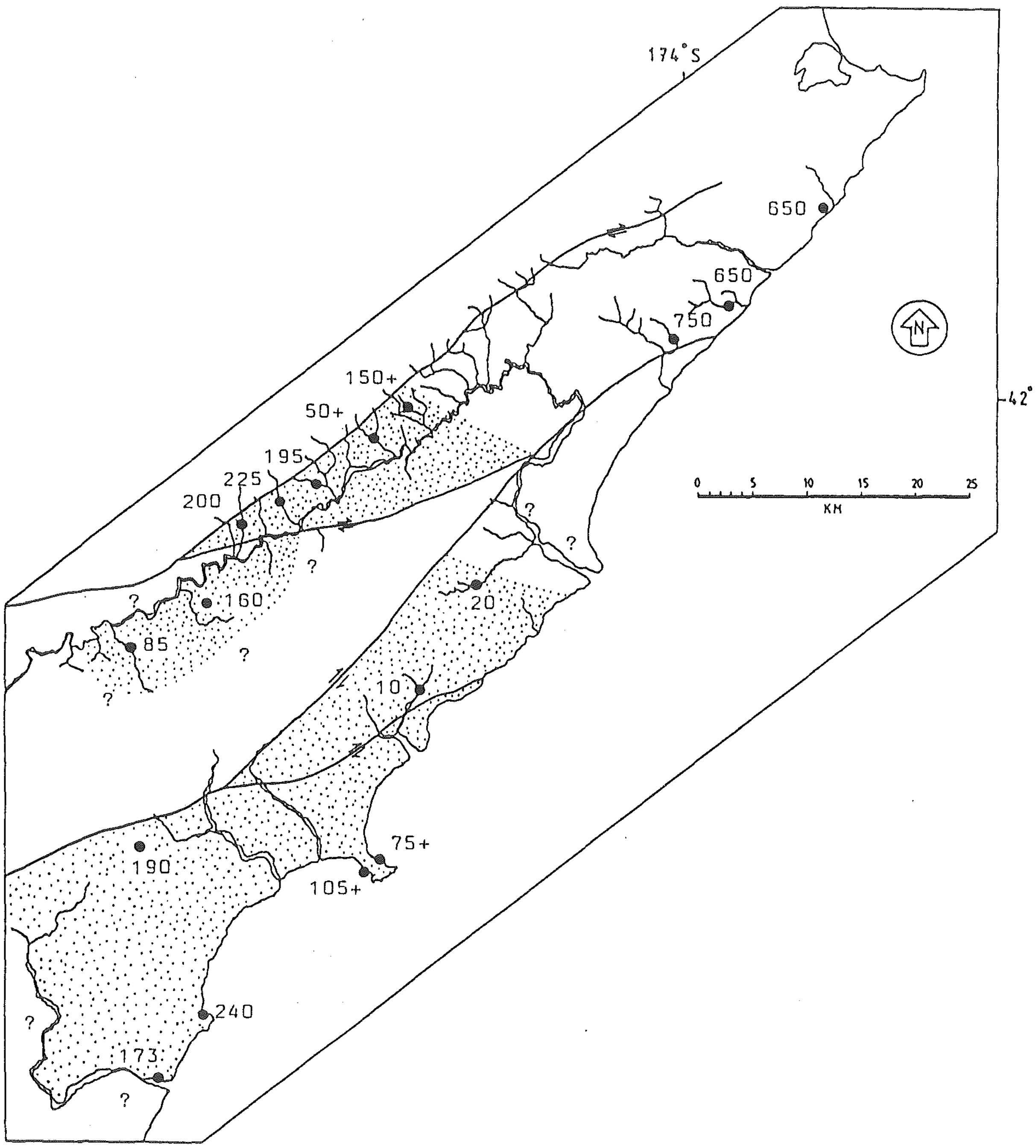


Figure 3.1.1: Preserved thicknesses (m) of the Woolshed Formation. Data from Webb (1966), Lensen (1978a), Warren & Speden (1978), Reay (1980), and personal observations. Stippled areas show extent of erosional upper surface beneath Claverley Sandstone.

Webb's definition of the Woolshed Formation is expanded in this thesis to include dark grey, poorly indurated, massive to cm-bedded, sulphur efflorescent, poorly fossiliferous, non-calcareous, very fine sandy siltstones. The presence of interbedded cm- to m-thick sandstones or chert lenses is not essential to the definition.

Near Flaxbourne River, the Woolshed Formation is divided stratigraphically into upper and lower parts by the Flaxbourne Limestone Member of the Mead Hill Formation (see Chapter 4.1).

Distribution And Thickness

Regional variations in the thickness of the Woolshed Formation indicate trends in basinal development prior to deposition of the Mead Hill Formation. The outcrop pattern of the Woolshed Formation parallels that of the Amuri Limestone (Figure 1.5), except where the unit is faulted out between Branch Stream and Coverham. Preserved thicknesses are shown in Figure 3.1.1, but the lack of sufficient data points and other variables (e.g. differential erosion of the upper surface) precludes the construction of a paleoisopach map.

The unit maintains a relatively constant thickness of c.200m in the Clarence valley, reaching a maximum of 225m in Bluff Stream and a minimum of 85m in Seymour Stream (Reay 1980). Similar thicknesses are recorded south of the Hope Fault. According to Warren & Speden (1978), the Woolshed Formation varies from 240m at Haumuri Bluff to between 150m and 180m near the mouth of the Conway River. The Formation is 190m thick near Monkey Face (Crampton 1985). Generally thinner sequences are reported to the south of the study area in North Canterbury (Browne & Field 1985).

The Woolshed Formation attains its maximum thickness in the vicinity of Ben More Stream, where Webb (1966) and Lensen (1978a) agree on a value of c.750m. Prebble (1976) recorded a value of 650m in Woodside Creek. Price (1974) estimated thicknesses for the Mirza and Butt Formations (lower and upper Woolshed Formation) of 450m and 250m respectively. Similar figures (310m and 290m) were quoted by Lensen (1978a).

The thickness of Woolshed Formation between the mouth of the Clarence River and Kaikoura Peninsula is greatly attenuated. The Formation is no thicker than 10m in Puhi Puhi River (near its confluence with Jordan Stream) and is approximately 20m thick in Wharekiri Stream. At the latter locality, there is good evidence to suggest prolonged non-deposition prior to deposition of the overlying Claverley Sandstone (see Chapter 3.2).

The Woolshed Formation forms a blanket of relatively uniform thickness throughout the southern half of the study area. The presence of an erosional upper surface in these areas may account for the minor variations in thickness. Accepting later differential erosion, it is likely that the original veneer (c.250m) was even more uniform. The Formation thickens abruptly north of Branch Stream, and is c.700m thick throughout the northern part of the study area.

Relation To Underlying Rocks

In the vicinity of Haumuri Bluff, the Woolshed Formation overlies the near-shore, shallow water Tarapuhi Grit (lowermost Haumurian) with a relatively sharp but conformable contact (Warren & Speden 1978).

In central regions of the study area, the basal contact of the unit is marked by a strong angular unconformity on mid Cretaceous rocks. The "basal shell bed" recognized by Suggate (1958) was interpreted as an exhumed (Arowhanan) lens at the top of the underlying Gridiron Formation by Reay (1980). In Wharekiri Stream, the basal contact is not obvious but is likely to be an unconformity, because only c.20m of (Haumurian) Woolshed Formation overlies much older (Ngaterian) glauconitic sandstones (M. Laird, NZGS, pers. comm. 1986).

On the east flank of Mt. Alexander, the base of the Woolshed Formation is conformable on a c.10m thick glauconitic sandstone of unknown age. The Woolshed Formation conformably overlies a very similar, 10-35m, highly glauconitic sandstone (Paton Formation) in the Coverham - Ben More Stream area (Webb 1966; Prebble 1976; Lensen 1978a). It is suggested here that the Paton Formation is unconformable on Lower Iwitahi Group rocks, although both Hall (1964) and Prebble (1976) have stated that its base is conformable.

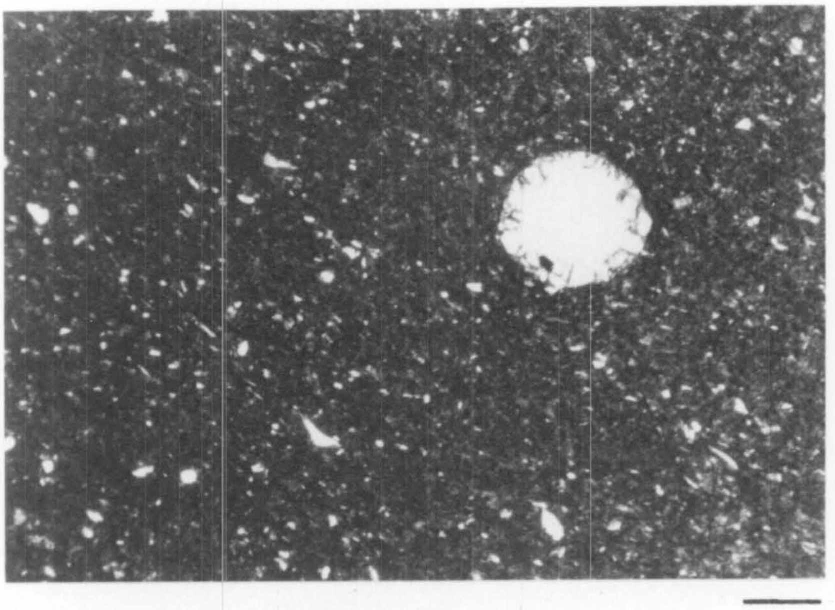
Type Section

The type section for the Woolshed Formation (Webb 1966) in Ben More Stream extends from the top of the calcareous, glauconitic sandstones that Webb informally named "*Black Grit*" (Paton Formation) up to the base of the overlying Mead Hill Formation. The limits of this stratotype vary from MacPherson's (1952) original definition in that they specifi-

Figure 3.1.2: Thin section photomicrograph (uncrossed polarizers) of Woolshed Formation , showing cross-sectional view of *Terebellina*. Scale = 0.25mm.

Figure 3.1.3: Thin section photomicrograph (uncrossed polarizers) of Woolshed Formation. Scale = 0.25mm.

Figure 3.1.4: Thin section photomicrograph (uncrossed polarizers) of dolomite concretion in Woolshed Formation. Note anhedral xenotopic texture. Scale = 0.25mm.



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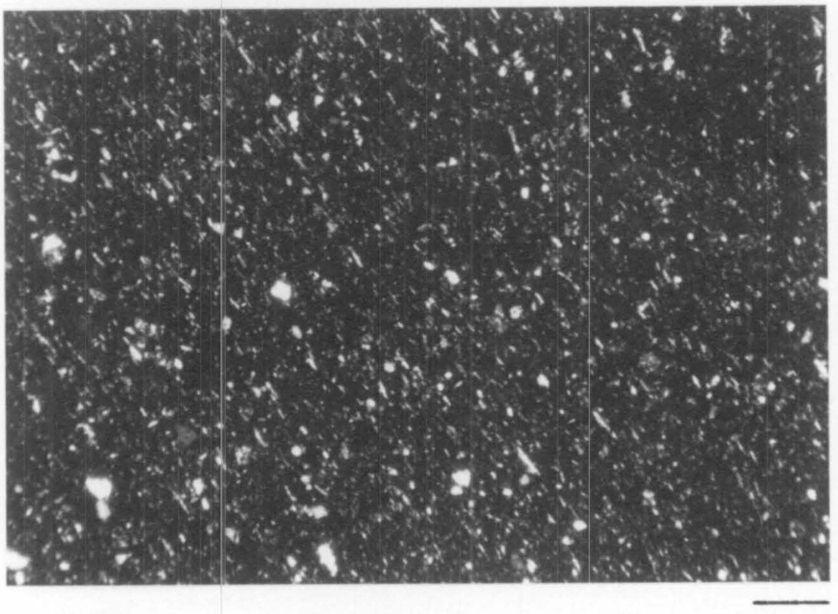

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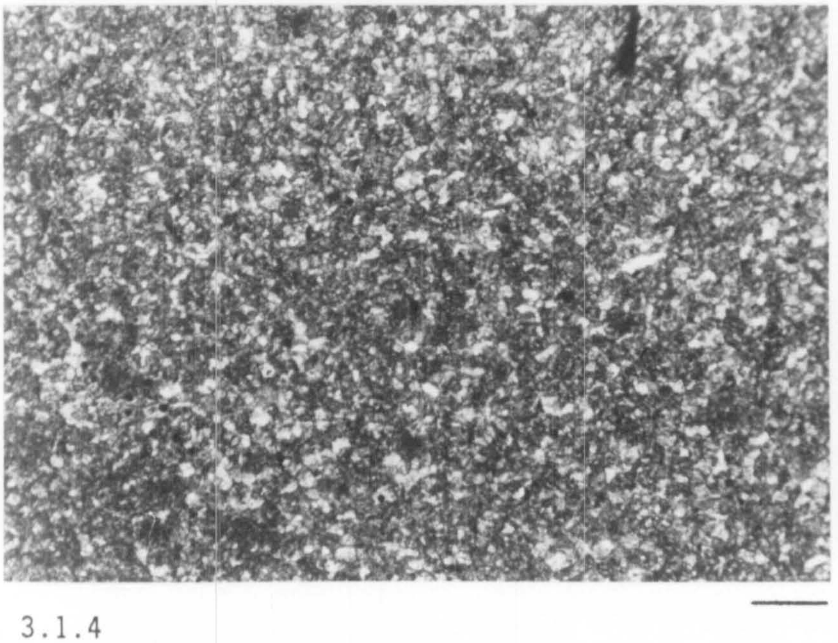


3.1.4

cally exclude the Paton Formation. Prebble (1976) considered the Woolshed Formation near Ben More Stream to be identical to the Whangai Shale, for which the type section is in Te Uri Stream in the North Island.

Webb neglected to include grid references, but from his stratigraphic description it is clear that he intended the type section to extend from S35/271447 at the base of the Formation downstream to S35/277436 at the top.

Lithology

The Formation is typically light to medium grey and often masked, most noticeably on weathered surfaces, by a light yellow coating of jarosite which is regionally distinctive of the unit. Induration is usually poor, except in rare cases (e.g. Kaikoura) where silica cementation has produced a moderately well indurated lithology.

Carbonate cement is generally absent, except in concretions (Figure 3.1.4). Where the unit is directly overlain by Mead Hill Formation (e.g. Isolation Creek), dolomite can locally be an important constituent in the form of massive pods or layers rather than as disseminated cement. The total carbonate (mean: 6wt%) is apparently below the limits of XRD detection.

No systematic grain size determinations were made on the unit as part of this study. Field observations and thin section examination, combined with data from Warren & Speden (1978) and Reay (1980), show that the dominant lithology is a very poorly sorted, finely skewed, very fine sandy siltstone. Although sand comprises up to 20% of the sediment, the maximum grain size rarely exceeds very fine sand (Figure 3.1.3). The clay fraction (>8ø) totals 20-30% of the overall distribution.

Mineralogically, the sand and coarse silt size population is dominated by monocrystalline quartz with minor amounts of fresh albite. Large micas are conspicuously absent; grains of medium silt or finer are mainly clay minerals. XRD analysis indicates that these clays consist of illite with lesser amounts of smectite and kaolinite (Appendix II). Some of the larger clay flakes seen in thin section may be illite derived from degraded micas.

Glauconite, although a very minor component (<0.1%), is generally present in most thin sections. The sequence immediately overlying the Flaxbourne Limestone near the mouth of the Flaxbourne River contains up to 10% glauconite.

Most samples contain 1-2% pyrite in grain sizes ranging up to very fine sand. In Dart Stream, rare intercalated 1-10cm thick, calcareous, very fine sandstones are pyrite-cemented.

The most abundant diagenetic mineral, apart from concretionary carbonate, is silica. This mineral is present either in the form of opal-CT (Appendix II & G.J. van der Lingen, NZGS, pers. comm. 1985) or as microcrystalline quartz. On the south side of Kaikoura (Appendix IV: JM 24), 18m of siltstone is cemented into a single, massive bed by opal-CT (cristobalite). At Whernside Spur (c.5km NW from Ben More Stream), c.20m of interbedded (dcm-scale) chert and siliceous siltstone is intercalated approximately 50m below the base of the Mead Hill Formation. XRF analysis (Appendix II) shows that the Woolshed Formation has a relatively high whole rock SiO_2 total (mean: 77.5%), compared with average shale values (58.5%) quoted by Veizen (1983).

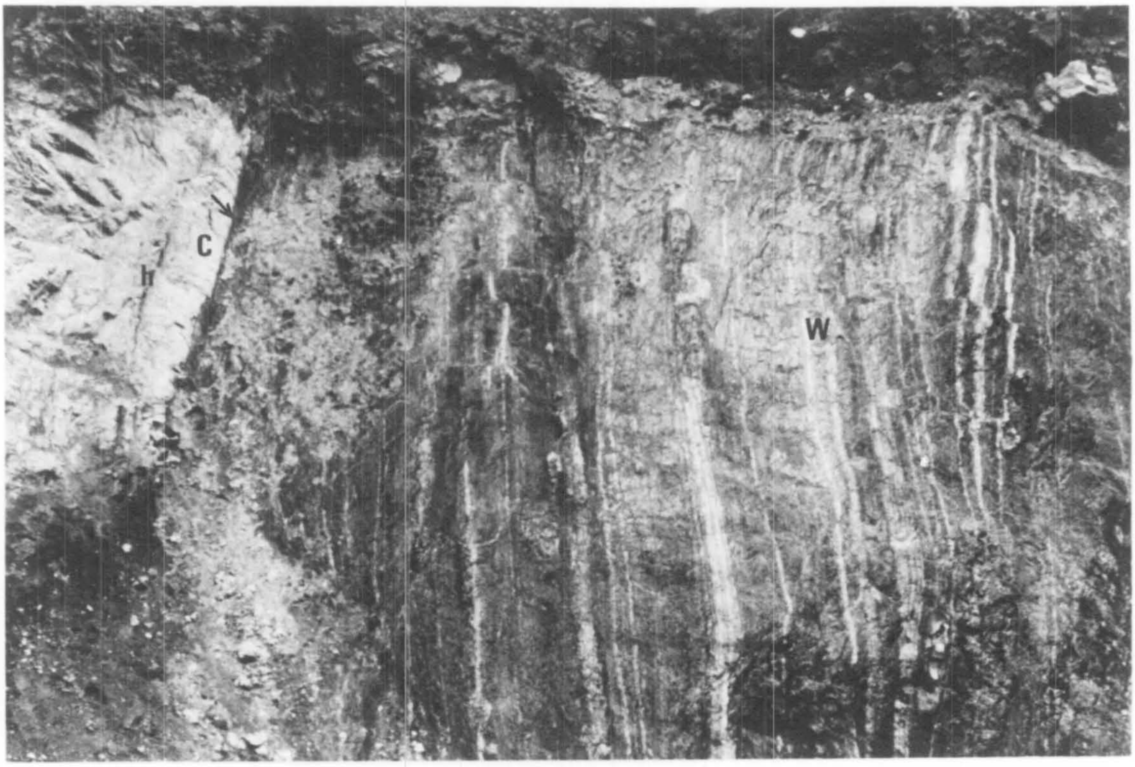
Large carbonate concretions, which characterize the Woolshed Formation throughout Marlborough, have been described briefly by Warren & Speden (1978) and in more detail by Browne (1985). Flattened dolomitic concretions, commonly in excess of 3m in diameter (maximum recorded 6m) and 1-2m thick, are concentrated along surfaces parallel to bedding. South of Kaikoura, concretions are typically spherical and calcitic. At most exposures, concretions occupy <1-2% of the total volume of the enclosing sediment. Remnant or "ghost" bedding surfaces commonly continue through the concretions and differential compaction is a common feature (Figure 3.1.8).

The matrix of the dolomite concretions consists of interlocking 0.05mm anhedral crystals with irregular intercrystalline boundaries and undulatory extinction (Figure 3.1.4). Larger coarse silt or fine sand sized detrital grains are preserved within the carbonate matrix.

Warren & Speden (1978) recovered reptilian bones, molluscan shells and wood fragments that were preserved inside concretions at Haumuri Bluff. One sample recovered from 65m below the top of the Woolshed Formation in Branch Stream contained a well preserved thin-shelled bivalve.

Figure 3.1.5: Unconformity (arrowed) between Claverley Sandstone (c) and Woolshed Formation (w). Branch Stream (S42/007375). Note dcm-thick intercalations of fine sandstone in Woolshed Formation, and carbonaceous horizon (h) near base of Claverley. Width of outcrop is approximately 40m. Younging direction is from right to left. *Photo: M. Lawrence.*

Figure 3.1.6: Flysch facies of Woolshed Formation. Woodside Creek (S36/336467). Note 3m thick channelized sandstone at centre. Figure at bottom, right for scale.



3.1.5

3.1.6

Prebble (1976) and H. Wellman (pers. comm. 1985) reported ammonites from dolomite concretions in Isolation Creek.

In southern outcrops (e.g. Haumuri Bluff), bedding in the Woolshed Formation is indistinct, principally because of bioturbation. Primary stratification becomes more pronounced further north as the intensity of bioturbation decreases. Inland Clarence valley sections are characterized by finely interbedded or laminated dark and light coloured siltstone (Figure 3.1.5).

At Kaikoura, Browne (1985) and Browne & Field (1985) describe the Woolshed Formation as alternating cm- to dcm-bedded sandstone and mudstone. Whereas the dcm-scale bedding can easily be distinguished in outcrop, thin section examination failed to detect any significant grain size variation between beds. The only lithologic differences are slight variations in colour and induration. XRD analysis showed that the more indurated beds have been preferentially cemented by cristobalite.

South from Branch Stream, interbedded 5-50cm thick, very fine to fine sandstones are relatively common and are easily recognized, but rarely constitute more than 10% of the total section (Figure 3.1.5). Sandstone beds are more closely spaced and become thicker upwards. Most sandstones are texturally well sorted, angular, very fine sands and compositionally subfeldsarenitic (Appendix III; Chapter 6.1).

Typical sedimentary structures within the siltstone include laminations, small-scale convolutions, ripples, and possible cm-scale flaser bedding. Grading is generally absent; the dcm-scale cross-bedding reported by Browne & Field (1985) at Kaikoura was not observed. Reay (1980) describes angular rip-up clasts within interbedded sandstones in the Woolshed Formation in Seymour Stream. He also mentions the presence of local trough cross-stratification, but this occurs in lithologies interpreted to occur within the overlying Claverley Sandstone.

The Woolshed Formation generally coarsens northward. Intercalated fine sandstones become more common, and at Woodside Creek comprise >30% of the total thickness of the Formation. These sandstones (Figure 3.1.6), which were described and named by Prebble (1976) as "*Flags Formation*", display features indicative of a turbidite origin (e.g. flutes, Bouma sequences). Individual beds commonly exceed 2m in thickness and occur within 30-60m thick sandstone-dominated stratigraphic packages,

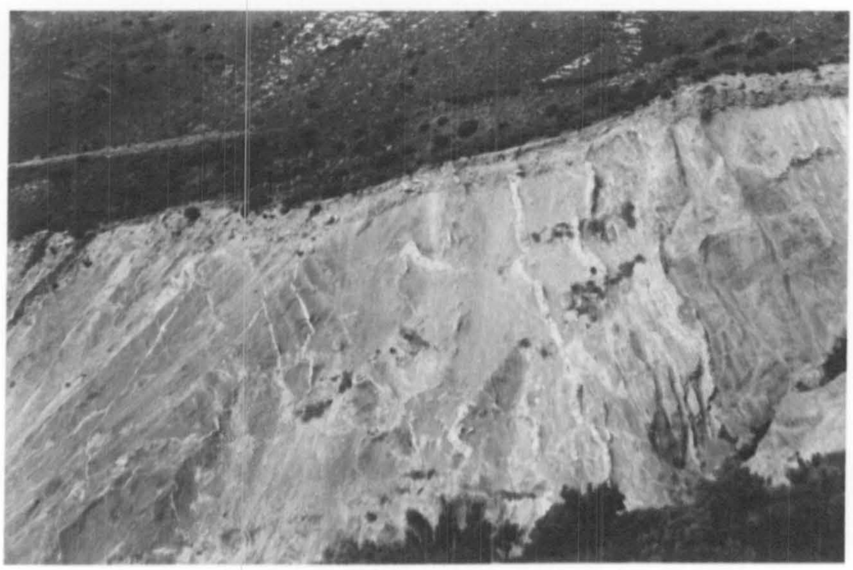
Figure 3.1.7: Laminated, sandstone-poor facies of Woolshed Formation. Woodside Creek (S36/336467).

Figure 3.1.8: Large dolomite concretion in Woolshed Formation. Branch Stream (S42/007375). Note internal preservation of bedding. *Photo: M. Lawrence.*

Figure 3.1.9: Anastomosing clastic dikes cutting Woolshed Formation. Branch Stream (S42/008373). Width of outcrop is approximately 200m.

3.1.7

3.1.8



3.1.9

altogether totalling 200m. Each package is separated by c.10m sandstone-free intervals and the entire sandstone-rich sequence is enclosed above and below by c.200m of sandstone-poor siltstones. These sandstones (sublitharenites) are compositionally less mature than those to the south (Appendix III; Chapter 6.1).

Much of the increased thickness of the Woolshed Formation in northern areas can be explained by the presence of the additional volume of sandstone. The basal c.100m of Woolshed Formation overlying the Flaxbourne Limestone between Chancet Rocks and Needles Point may correlate with the flysch-like interval at Woodside Creek. The former sequence is composed of 50-100m of m-bedded, graded, glauconitic sandstones which pass upward into slightly sandy siltstone underlying the main body of the Mead Hill Formation.

Anastomosing networks of clastic dikes are an almost ubiquitous feature of the Woolshed Formation (Figure 3.1.9). Intrusions are up to 1m wide, but are usually on the order of 10-20cm, and occur at all orientations, although most are sub-vertical with respect to bedding. Dikes can be traced for at least 100m perpendicular to stratification and commonly cross-cut sandstone beds. Internal sedimentary features are lacking and the sandstone matrix is usually massive. The composition of the dike sandstone is similar to that of the intercalated sandstone beds (Appendix III; Chapter 6.1). At Kaikoura, a 5cm wide clastic dike cuts and therefore postdates dolomite concretions. Dikes are more common in the lower part of the Formation and tend to thin out upwards or occasionally terminate (though not erosionally) against the base of sandstone beds.

Ichnology

The intensity of bioturbation in the Woolshed Formation generally decreases northward and ranges from total obliteration of all other sedimentary structures (e.g. Haumuri Bluff) to the virtual absence of burrows (e.g. Woodside Creek). Only cross-sectional views of burrows are usually visible because exposure of bedding plane surfaces is uncommon. Burrows are generally small and irregular, and rarely extend more than a few cm downwards. Few recognizable ichnogenera were observed; an anomalous specimen of *Zoophycos* is shown by Warren & Speden (1978).

Terebellina is relatively common in most exposures as a 1mm diameter white ring or ellipse. This ichnogenus consists of a hollow tube with walls built of a layer of very fine sand or coarse silt only one grain thick (Figure 3.1.2). Individual grains are equant and are always extremely well sorted. The grain size is equivalent to that of the coarsest fraction of the sediment.

Paleontology

The macropaleontology of the Woolshed Formation at Haumuri Bluff has been discussed in detail by Warren & Speden (1978). The sparse macrofaunal assemblage at that location is typical of the Formation throughout the study area. Macrofossils, which are mainly preserved in the large concretions, are predominantly reptile bones (Plesiosaurs and Mososaurs) but also bivalves (mainly pectins) and cephalopods. Apart from rare, possibly reworked *Dimitobelus hectori*, the Woolshed Formation at Haumuri Bluff lacks macrofauna suitable for detailed correlation. Browne (1985) recorded one species of ammonite from the unit at Kaikoura. In situ specimens of both *Dimitobelus* aff. *hectori* and *Inoceramus matatorus*, as well as several species of ammonites, were recorded by Prebble (1976) from the Woolshed Formation in Ben More Stream and Isolation Creek.

A dolomite concretion with a calcareous core from Branch Stream yielded a complete articulated specimen of a *Tellinacean* bivalve.

An extensive study (Webb 1966) of the foraminifera from the Woolshed Formation showed that most species are arenaceous or siliceous benthics. Dead Horse Gully is the only locality where an exclusively calcareous taxa was recorded. Non-calcareous forms become more dominant passing northward, and north of Branch Stream and Wharekiri Stream calcareous foraminifera are entirely absent.

Webb originally divided the unit into a southern "Herring Formation" corresponding to his *Trochammina globigeriniformis* assemblage zone; and a northern Woolshed Formation equating with his *Rzehakina epigona* assemblage zone (both Haumurian). The boundary between these two Formations was placed at Branch and Wharekiri Streams. Although Webb (1971) later amended this definition to place the "Herring Formation" in the *R. epigona* zone, he retained the formational division. Webb's type section for the *R. epigona* assemblage zone is in Ben More Stream, where the upper and lower limits of the zone coincide with the boundaries of the Woolshed Formation.

Foraminifera from the sequence of Woolshed Formation overlying the Flaxbourne Limestone reportedly belong to the (upper Haumurian) *Globotruncana circumnodifer* assemblage zone (Webb 1971). However, the single sample (S36/f703) on which this classification is based may have been taken from the Flaxbourne Limestone itself.

Warren & Speden (1978) and Wilson (1983) note that the Woolshed Formation contains a rich microfloral assemblage including dinoflagellates, spores, pollen and plant fragments.

Age

All available paleontological data suggest that the Woolshed Formation in Marlborough is restricted to the Haumurian Stage (Appendix I).

Webb (1966, 1971) correlates his *R. epigona* assemblage zone with the Haumurian Stage. At Haumuri Bluff, the base of the Woolshed Formation lies approximately 20m above the base of the Haumurian, but a lengthy period of time may be represented by the intervening Tarapuhi Grit (Warren & Speden 1978). In thicker, more northerly sequences (e.g. Ben More Stream) the base of the Woolshed Formation coincides with the lower limit of the Haumurian.

The top of the Woolshed Formation (where not erosionally truncated and capped by the Claverley Sandstone or Teredo Limestone) is biostratigraphically marked by the incoming (or probable reintroduction, at Flaxbourne River) of calcareous foraminifera belonging to the upper Haumurian *G. circumnodifer* assemblage zone. At Haumuri Bluff, Wilson (1983) states that the base of the overlying Claverley Sandstone lies very close to the Cretaceous - Tertiary boundary. Elsewhere to the north (e.g. Woodside Creek), the Woolshed Formation is overlain by a considerable thickness (i.e. >90m) of late Haumurian strata, implying that the age of the top of the Formation in that area is probably not much younger than mid-Haumurian.

Ammonites {e.g. *Neophylloceras* sp. (O31/f138), *Maorites tenuicostatus* (S36/f1301, f1302), *Gunnarites denticulatus* (S36/f495, f1301), *Anagaudryceras subsacya* (S36/f1301, f1302), *Glyptoceras wakanenei* (S36/f1301)}, together with the Haumurian indicator fossil *I. matatorus*, confirm foraminiferal evidence.

Haumurian assemblages of dinoflagellates have been recovered from samples (O31/f230 and O32/f9534, f9535, f9536) of the Woolshed Formation at Monkey Face and Haumuri Bluff.

Facies Interpretation

A discussion of the inferred depositional environment of the Woolshed Formation at Haumuri Bluff was provided by Warren & Speden (1978). These authors suggested that the unit was probably deposited in a near-shore, marine basin with restricted bottom water circulation. A similar interpretation is adopted by Crampton (1985) at Monkey Face, and by Reay (1980) in the Seymour Stream area. Reay cites the paucity of microfossils as evidence for very shallow water depths (O31/f70). Euxinic conditions for the unit are favoured by these authors primarily because of the high pyrite and organic carbon content.

A poorly oxygenated, reducing environment may be inferred by the pyrite and organic carbon content, but it is unlikely that sea bottom conditions reached euxinic levels. The presence of bioturbation, although in some cases only slight, together with adult benthic macro-fauna and a diverse population of benthic foraminifera indicates that the amount of dissolved oxygen must have been at least as high as the threshold of survival of these organisms (i.e. 0.1 to 0.2 ml/l Savrda & Bottjer 1986). These limiting conditions suggest that the environment of deposition was more likely to have been dysaerobic, although probably less strongly so to the south, where the level of bioturbation is much greater.

A sea floor with a soft substrate was inferred from the paleoecology of the macrofauna by Warren & Speden (1978) at Haumuri Bluff. Exhumed concretions may have locally provided a firm or hard substrate for burrowing or boring organisms during the period of erosion and non-deposition prior to accumulation of the overlying Claverley Sandstone (see Chapter 3.2).

Paleobathymetric data for the bulk of the unit is poor, because of the paucity of benthic macrofauna and recognizable trace fossils. Several lines of evidence support a shallow water interpretation for at least the base of the Woolshed Formation in the southern half of the study area.

The Woolshed Formation in these areas either conformably overlies a very shallow water facies (Tarapuhi Grit) or rests directly on an erosional (probably subaerial in part) unconformity. In addition, Webb (1971) considered that the foraminiferal component of the "Herring Formation" (southern Woolshed Formation) represents an assemblage transitional from his *Trochammina globigeriniformis* assemblage zone, which he interpreted as representing a coastal lagoon or estuarine facies.

Browne & Field (1985) suggest that the Woolshed Formation at Kaikoura was deposited in a mid to outer shelf environment by high energy currents. No evidence was found during the course of this study to support such an interpretation. Sedimentary structures which include well preserved laminations, absence of grading and the poorly sorted, very fine grained nature of the sediment indicate that high energy currents were probably absent. Foraminifera from the overlying Mead Hill Formation at Kaikoura (031/f177, f181) indicate an inner shelf environment (C.P. Strong, NZGS, pers. comm. 1985) and it is unlikely that water depths in which that unit was deposited were significantly different to those of the underlying Woolshed Formation.

Further north, where the Woolshed Formation is much thicker, the sea floor may have been somewhat deeper. The relative abundance of ammonites suggests a more oceanic setting than that to the south. Webb's correlation of the *Rzehakina epigona* foraminiferal assemblage zone with European deep water flysch facies, together with Strong's (1977) upper slope facies (200-600m water depth) interpretation for the overlying Mead Hill Formation further supports a deeper water environment. Furthermore, in northern Marlborough, the Woolshed Formation conformably overlies the Paton Formation which has been interpreted as an outer shelf deposit (Hall 1964).

Sedimentation rates were relatively high. An overall minimum figure can be obtained for the Woolshed Formation at Haumuri Bluff, by dividing the total thickness of the unit (240m) by the estimated duration of deposition. Because the underlying Tarapuhi Grit is earliest Haumurian in age and the base of the overlying Claverley Sandstone is approximately equivalent to the top of the Haumurian, the period of accumulation cannot have exceeded 10m.y., based on current estimates of the length of the Haumurian Stage (Stevens 1981; Raine 1984). These figures give an overall rate of deposition of 24m/m.y. (or 24mm/1000y) at Haumuri Bluff. Similar reasoning, applied to the sandstone-poor intervals of the Woolshed Formation in Ben More Stream, produces a much higher minimum figure of 70mm/1000y. This higher figure may result partly from erosion of the upper surface at Haumuri Bluff.

These figures are neither absolute nor instantaneous because they do not recognize possible periods of non-deposition or erosion, and fail to consider the effects of compaction. However, because they are derived from essentially identical lithologies which have presumably undergone comparable degrees of compaction, comparisons can be made. The lower figure for the Woolshed Formation in the south, is consistent with its higher degree of bioturbation.

The proximity of the nearest shoreline is difficult to determine. Reay (1980) inferred SW-flowing paleocurrents, but these may be from the overlying Claverley Sandstone and are not necessarily a measurement of offshore-directed currents. Flutes from the soles of intercalated sandstone beds at Woodside Creek reportedly indicate derivation from the SW (Prebble 1976). At Waiau (30km inland from Haumuri Bluff), the Lagoon Stream Formation (which is partly coeval with, and lithologically similar to, the Woolshed Formation) passes laterally into the Stanton Conglomerate. This latter unit has been interpreted as a partly non-marine (fluviatile) deposit (Gregg 1965).

Data on the provenance of the Woolshed Formation is poor because of the paucity of sand-size grains in the siltstone. The very high SiO_2 content and significant quantities of kaolinite suggests derivation from a land surface undergoing prolonged chemical weathering (Waterhouse & Bradley 1957; Krauskopf 1979). Most of the silt was probably transported in dilute suspension currents and by wind.

A turbiditic origin for the flysch-like intercalated sandstones in northern areas is likely. If sediment gravity flows originated in shallow water to the SW, as suggested by the sparse paleocurrent data cited above and paleogeographic reconstructions (Stevens & Suggate 1978, p.733), then evidence recording their passage across the broad, intervening shelf should be preserved. Channelling, the feature which could be most expected, is absent from coeval Woolshed Formation sediments to the south. The more proximal nature of the graded sandstones overlying the Flaxbourne Limestone in the Chancet Rocks - Needles Point area, may support a northerly provenance and indicate a lateral shallowing trend (perhaps toward emergent land?) in that direction.

Isopach geometry and paleobathymetric data, together with differing rates and types of sedimentation, for the Woolshed Formation indicate that a major lateral facies change occurs between Branch Stream and Ben More Stream. In the southern Marlborough, the unit was deposited in an extensive, shallow water, poorly oxygenated (restricted?) shelf setting in which fine-grained sedimentation dominated. The rate of sediment accumulation in these areas is within the typical range (10-40mm/1000yrs) of passive continental margins suggested by Schwab (1976).

Siltstone sedimentation began in the north of the study area and spread very rapidly southward into progressively shallower water environments. Rapid spreading of facies is supported by the near isochroneity of the base of the Formation throughout southern Marlborough (Figure 2.1.2). The Woolshed Formation in northern Marlborough appears to have been deposited at a much higher rate and in a somewhat deeper part of the basin. These variations in sedimentation rates and basin morphology suggest more active basin subsidence and clastic sediment supply than in the south.

Essentially sand-free, detrital mud represented the steady-state supply of sediment throughout the basin. Coarser turbiditic influxes were superimposed on this background sedimentation. These northerly-derived sands ponded against a north-dipping (possibly fault-controlled?) slope which prevented their overspill onto the relatively sand-starved southern platform or shelf.

During deposition of the Woolshed Formation, Marlborough occupied a position close to the leading edge of the New Zealand continent (see Chapter 1). Because of its large distance from contemporaneous active rifting in the proto-Tasman Sea, passive subsidence rather than active block-faulting would have been the most likely tectonic environment. This subsidence, coupled with the existing low relief on the progressively developing peneplain (Stevens & Suggate 1978), would have facilitated rapid transgression.

Correlation

Wellman's (1955) correlation of the Woolshed Formation in Marlborough with the Whangai Shale in the North Island may still be valid. However, sufficient differences between the two units (M.B. Reay, NZGS, pers. comm. 1984) exist to prevent extension of the name southward into Marlborough. It is almost certain that the two units were once continuous and part of an extremely widespread facies.

Age and stratigraphic relations show that at least the upper part of the Woolshed Formation must be coeval with the lower part of the Mead Hill Formation. To the southwest of the study area, the Woolshed Formation passes laterally into the coeval Lagoon Stream Formation which interfingers with non-marine Stanton Conglomerate. The Woolshed Formation is time transgressive further southward, passing into shallow marine Loburn Mudstone (Teurian) which conformably overlies non-marine coal measures of the (Haumurian) Broken River Formation (Browne & Field 1985).

3.2 Claverley Sandstone (Formation)

Name And Definition

The Claverley Sandstone was originally defined at Haumuri Bluff by Warren & Speden (1978, p29) as "*pale yellow-brown and grey sandstone, mostly glauconitic and locally calcareous*" overlying the Conway Siltstone (Woolshed Formation) and underlying the Amuri Limestone.

The Claverley Sandstone is redefined here as a light grey, moderately indurated, intensively bioturbated or massive, well sorted, muddy, very fine to fine sandstone: slightly glauconitic, subfeldsarenite. The unit retains its lithostratigraphic status as a Formation.

Synonomy

Hector (1874):	"Greensand" and "Teredo Limestone"
Suggate (1958):	the uppermost member of the "Seymour Formation"
Wellman (1959):	"Upper Teredo Limestone"
	"glauconitic sandstone"
	"Lower Teredo Limestone"
Webb (1966):	"Mead Hill Formation"
Warren & Speden (1978):	"Claverley Sandstone" including "Upper Teredo Limestone"
Reay (1980):	"Dip Basin Greensand"

Distribution And Thickness

The Claverley Sandstone extends from at least as far south as Conway River, northward to Mororimu Stream on the coast and Branch Stream inland (Figure 3.1.1). North of these latter two localities, its stratigraphic position is either faulted out and/or not exposed until near Ben More Stream, where the Mead Hill Formation rests conformably on the Woolshed Formation. The Claverley Sandstone must therefore pinch out somewhere in this c.25km interval. At Monkey Face and Limestone Hill, the Formation is absent and much younger Teredo Limestone unconformably overlies the Woolshed Formation.

The unit attains a maximum depositional thickness of 40m in Puhi Puhi River, and a minimum of 50cm in Bluff Stream (Figure A1). The average thickness of the Formation throughout the study area is c.10m. No consistent pattern in isopach distribution is recognizable at a regional scale.

Relation To Underlying Rocks

The Claverley Sandstone everywhere overlies the Woolshed Formation, and the boundary is probably always unconformable. The basal contact is usually a sharp, concordant surface between the poorly indurated, medium to dark grey, thinly bedded siltstones below (Woolshed Formation) and moderately indurated, light grey or tan, generally massive, fine sandstone above. A locally burrowed base and/or a coarse basal layer provide the main evidence for an unconformable contact. There is no outcrop scale discordance with, or scouring into, the upper surface of the Woolshed Formation. With several exceptions, the base of the Claverley Sandstone is generally devoid of either current-generated or biogenic sole marks.

The base of the Formation is defined as being either above the highest intercalation of Woolshed Formation or, where a significant non-depositional and/or erosional horizon can be recognized (as occurs at Kaikoura), at the base of a stratigraphically lower sandstone. This definition differs from that of Browne & Field (1985), who suggest that the contact with the Woolshed Formation be arbitrarily set at the level of equal amounts of interbedded sandstone and siltstone.

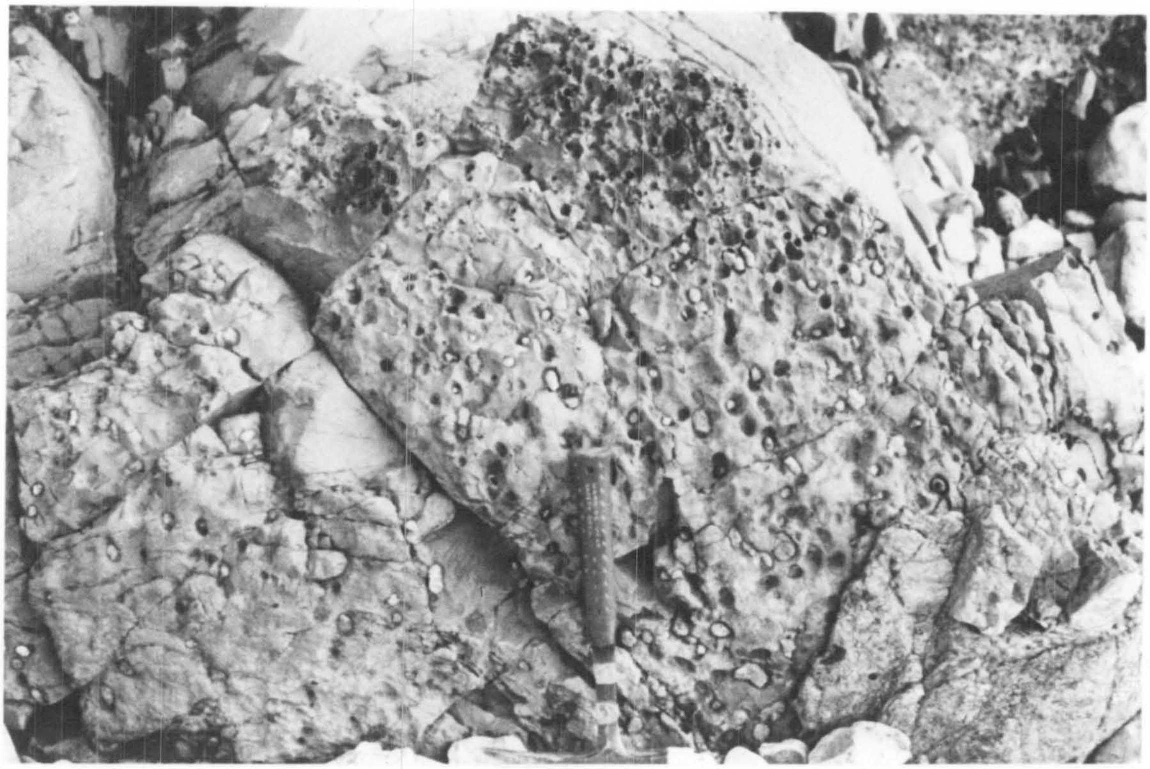
Type Section

The stratotype of the Claverley Sandstone was designated by Warren & Speden (1978) as the section from the top of the Conway Siltstone (Woolshed Formation) at S55/799730 up to the contact with the overlying Amuri Limestone on the north face of Haumuri Bluff. These authors clearly intended the type section to extend to the top of the Teredo Limestone. If this section is to be retained as the stratotype, then the Formation should only extend up as far as the base of the Teredo Limestone.

This section is abandoned as the stratotype because the lower contact is not clearly exposed and the upper contact is an erosional unconformity. The lectostratotype is exposed in the north fork of Dart Stream, near the base of a 6m waterfall at S42/973340 (Appendix IV: JM 42). The Claverley Sandstone extends from the sharp, planar contact with the underlying Woolshed Formation up to the sharp contact with the overlying Mead Hill Formation (Figure 3.2.8). The Formation consists of 8m of light brownish grey, well indurated, massive, well sorted, muddy fine sandstone: calcite cemented, subfeldsarenite (Appendix III: JM 10/3).

Figure 3.2.1: Bored and phosphatized outer margin of exhumed and reworked dolomite concretion in Claverley Sandstone. Kaikoura Peninsula (S49/978898). Burrows infilled with microcrystalline cristobalite or quartz.

Figure 3.2.2: Large scale climbing convolutions and poorly defined stratification in Claverley Sandstone. Bluff Stream (S42/884255). Hammer for scale.



3.2.1

3.2.2

Reference Sections

1. *Conway River Mouth* (S55/756668)

10m of light greenish grey, moderately indurated, massive, very well sorted, fine sandstone: slightly glauconitic, subfeldsarenite (Appendix III: JM 6/4) is exposed in the rail cutting near the mouth of the Conway River (Appendix IV: JM 6). The section is analogous to the holostratotype at Haumuri Bluff insofar as the Claverley Sandstone has unconformable contacts with the Woolshed Formation (below) and Teredo Limestone (above) (Figure 4.2.10). Crude stratification is defined by layers of phosphatic pebble-size clasts and quartz granules.

A 10m thick intercalation of sandstone occurs 10-20m below the top of the Woolshed Formation. This sandstone is compositionally and texturally very similar to the Claverley Sandstone. However, the unit has conformable contacts with the Woolshed Formation, no anomalous coarse lag horizons, and displays dcm-scale cross-stratification, with ripples preserved in relief on exposed bedding surfaces.

2. *Kaikoura Peninsula* (S49/978898)

The basal 10m of Claverley Sandstone is exposed between the shore platform and the road on the north side of Kaikoura Peninsula (Appendix IV: JM 4). A 2m thick disrupted interval of light greyish green, well indurated, well sorted, very fine sandstone: glauconitic, subfeldsarenite abruptly overlies Woolshed Formation. Small (1cm diameter) burrows extending several cm into the underlying siltstone are infilled with sandstone. The outer surfaces of large dolomite concretions within this interval have been extensively bored and partially phosphatized (Figure 3.2.1). Similar concretions in the underlying Woolshed Formation have a smooth exterior.

This lowermost interval is gradationally overlain by 2m of dark grey, non-calcareous siltstone, similar in lithology to the underlying Woolshed Formation. This siltstone grades up into >5m of light medium greyish green, well indurated, nodular bedded, well sorted, muddy, very fine sandstone: micritic, glauconitic, subfeldsarenite (Appendix III: JM 4/1, JM 4/2). The outcrop appearance and matrix composition of this upper sandy interval are similar to those of the overlying Mead Hill Formation. The upper contact is obscured beneath the adjacent road surface but is assumed to be gradational because the Formation becomes less sandy and more micritic upwards.

3. *Dead Horse Gully* (S42/910290)

The Claverley Sandstone comprises 80cm of light grey, moderately indurated, poorly bedded, bioturbated, well sorted, very fine sandstone: calcite cemented, glauconitic, subfeldsarenite (Appendix IV: JM 43A). Contacts with the underlying Woolshed Formation and overlying Mead Hill Formation are sharp. The Claverley Sandstone is anomalously calcareous and contains up to 30% pyrite disseminated throughout the upper 50cm. Stratification is defined by intercalated 5mm lenses of very glauconitic sandstone and 10mm layers of medium to coarse sand. The uppermost 25cm is a sedimentary breccia consisting of angular, cm-size chert and micritic limestone fragments floating in a sandstone matrix.

4. *Branch Stream* (S36/336467)

The most northerly exposure of Claverley Sandstone occurs at Branch Stream (Appendix IV: JM 40B) where approximately 5m of Claverley Sandstone abruptly overlies Woolshed Formation (Figure 3.2.5). Several 1-10cm, very carbonaceous siltstone layers are present in an unusually carbonaceous, but compositionally and texturally typical, Claverley Sandstone lithology. Carbonaceous horizons are composed of redeposited, finely comminuted, plant fragments with no evidence of in situ root growth or paleosol development. The upper contact with the overlying Mead Hill Formation is discordant and is marked by a 20cm thick, highly carbonaceous mudstone horizon containing crushed fragments of micritic limestone.

Lithology

Weathered Claverley Sandstone is generally light brownish grey; freshly broken surfaces are various shades of light to medium grey. The sediment is generally moderately to well indurated, although only rarely cemented. The lithology is typically non-calcareous (mean: wt% $CaCO_3$ <5%), except where it is gradational with the overlying Mead Hill Formation, where a significant quantity (<50%) of micritic matrix may be present.

At Mororimu Stream and in Puhi Puhi River, both chert and dolomite extend down into the Claverley Sandstone from the overlying Mead Hill Formation. In these cases the chert is present as sporadic nodules but locally cements up to 50% of the total volume of rock (see M. Lawrence, in prep.).

With the exception of bioturbation structures, the Claverley Sand-

Figure 3.2.5: Claverley Sandstone unconformably overlying overlying Woolshed Formation, and in probable fault contact with overlying Mead Hill Formation. Branch Stream (S36/336467). Note wedge of carbonaceous mudstone between Claverley Sandstone and Mead Hill Formation.

3.2.5

stone is usually massive in both outcrop and thin section. The general absence of primary sedimentary structures may be a direct result of biogenic homogenization, which commonly occurs to such an extent that individual burrows are indistinguishable. Bedding is rarely present as indistinct 10cm beds which mimic the style of bedding in the overlying Mead Hill Formation (e.g. Figure 3.2.7). At Mororimu Stream, the Claverley Sandstone contains 10cm-thick, well defined couplets of intensely bioturbated and thinly laminated sandstones. Reay (1980) described cross-bedding in the Claverley Sandstone in Seymour Stream. In Bluff Stream, m-scale climbing convolutions are locally present (Figure 3.2.2). Paleocurrent indicators such as flute casts were not observed at any outcrop.

In Wharekiri Stream, the basal 1-2m of Claverley Sandstone contains a matrix-supported breccia of large (<50cm), angular blocks of Woolshed Formation and well rounded granules and pebbles of assorted, well indurated lithologies. An intensive network of 1cm diameter *Thallasinoides* burrows is exposed in hyporelief on the basal surface (Figure 3.2.6). Burrows do not extend down into the underlying Woolshed Formation except as concave grooves formed in epirelief. Both the bioturbated surface and the breccia layer are traceable for several hundred metres along strike.

In lower Bluff Stream, the basal 30cm of Claverley Sandstone contains a sparse, matrix supported, normally graded, poorly sorted population of well rounded, very coarse sand to pebble size clasts. Up to 50% of the clasts have a phosphatized outer margin and shark's teeth are common. This coarse layer is localized and cannot be traced further than a few metres laterally.

In Seymour Stream, where sandstone beds in the Woolshed Formation increase in both frequency and thickness upwards into the Claverley Sandstone, the basal contact appears transitional. However, closer examination of the base of the unit shows a phosphatic, granular layer and an anomalous 5mm layer of gypsum above the contact. The base of the Claverley Sandstone at this location, is immediately above the highest stratigraphic intercalation of "Woolshed-type" siltstone.

In the case of the Conway River reference section (Appendix IV: JM 6), the lower 10m interval of Claverley-like sandstone is probably conformable within the Woolshed Formation. This interval probably represents an anomalously thick intercalation of sandstone similar to thinner interbeds common lower in that Formation.

The textural and compositional petrography of the Claverley is described in detail in Chapter 6.1.

Paleontology

The Claverley Sandstone is characteristically unfossiliferous. A small, but generally non-specific, macrofaunal list for the Claverley Sandstone near Haumuri Bluff is provided by Warren & Speden (1978). This list includes crinoid and echinoid remains, large bivalves, a large patellid gastropod, barnacles, fish vertebrae, several brachiopods and belemnites. They also include Clavigellid bivalve tubes, but these are restricted to the overlying Teredo Limestone (see Chapter 4.2).

The only macrofossils recovered from the Claverley Sandstone during this study, were a single rugose coral (*Dasmosmilia*: S55/f507) and a bored bivalve cast.

When processed for extraction of foraminifera, most samples collected during this study proved barren, with the exception of P31/f40, which contained a good calcareous fauna. Thin section examination indicated that many samples contain very sparse but relatively well preserved, large, thick walled, calcareous foraminifera. Planktonics generally exceed benthics in number. Large (<0.5mm diameter), very well preserved sponge spicules are a relatively common, though minor, biogenic component.

Webb (1966) was able to extract foraminifera from the Claverley Sandstone at several locations in Marlborough. He considered the fauna were part of his *Globotruncana circumnodifer* assemblage zone, and on that basis established the base of the Mead Hill Formation at the base of the Claverley Sandstone.

A good assemblage of dinoflagellates was extracted from the base of the Formation at Haumuri Bluff by Wilson (1983).

Ichnology

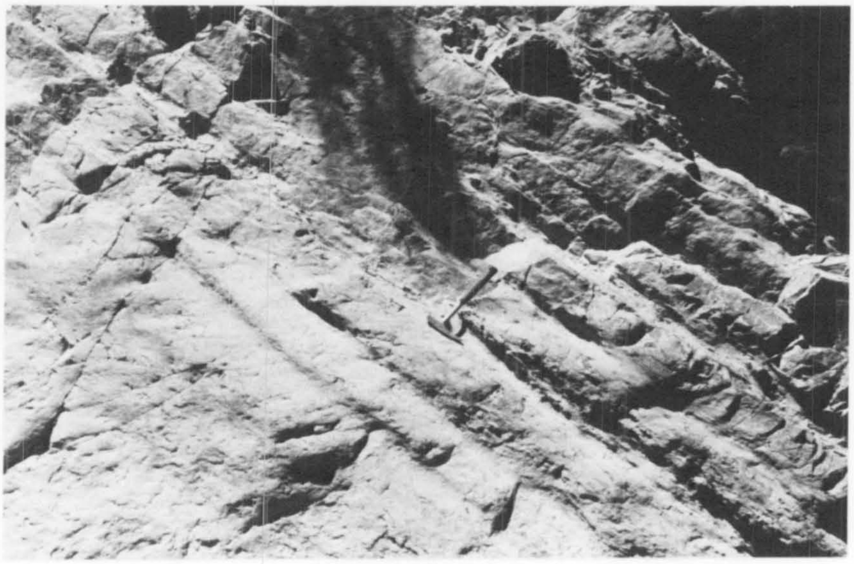
Possibly because of the well sorted nature of the sediment, individual trace fossils are rarely visible. In many outcrops, intense bioturbation has produced a mottled texture. The dominant ichnogenus is

Figure 3.2.6: *Thallasinoides* exichnia exposed on base of Claverley Sandstone. Wharekiri Stream (S42/087192). Lens cap for scale.

Figure 3.2.7: Gradational contact between Claverley Sandstone (left) and Mead Hill Formation (right). Wharekiri Stream (S42/087192).

Figure 3.2.8: Type section of Claverley Sandstone. Dart Stream (S42/973340). Woolshed Formation (W). Mead Hill Formation (M). c.f. Figure 4.2.11.

3.2.6



3.2.7

3.2.8

Thallasinoides (1-2cm diameter) which is rarely preserved as silicified burrows, or exposed in relief on the base of the unit. Clavigellid (=*Teredo*) tubes are absent from the Claverley Sandstone.

Age

The Claverley Sandstone throughout eastern Marlborough is late Haumurian in age*. The presence of very rare *Dimitobelus hectori* (Haumurian diagnostic) together with the identification of late Haumurian (*G. circumnodifer*) microfauna (S42/f669, f681) and dinoflagellates (S55/f518A) at sporadic localities, represent the bulk of age determinative data. Wilson (1983) considered the assemblage from the base of the Claverley at Haumuri Bluff to be uppermost Haumurian.

Reay (1980) provides a foraminiferal list for the "Dip Basin Greensand" in the Seymour Stream area, which is in part equivalent to the Claverley Sandstone. It is likely that many of the listed microfauna represent sampling from the overlying, much younger Teredo Limestone. A single sample (O31/f70), which is certainly from the Claverley Sandstone, indicates that the unit is also Haumurian in that area.

The Haumurian age derived from P31/f40, at the top of the Claverley in Puhi Puhi River, is the only successful determination for the unit made during this study. Numerous other samples that were processed for foraminiferal extraction were barren.

Indirect evidence from the underlying and overlying Formations further indicates a late Haumurian age. Because everywhere the Claverley Sandstone overlies Woolshed Formation of definite Haumurian age, the lower age limit is well constrained. The base of the conformably overlying Mead Hill Formation is dated as late Haumurian. There appears to be very little variation in age for the unit throughout Marlborough. The total duration of deposition is unlikely to have exceeded 1m.y., based on the thickness of the enclosing upper Haumurian strata.

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*C.P. Strong, NZGS, pers. comm. 1987 has reported that Teurian - Waipawan calcareous nannofossils have been recovered from near the top of the Claverley Sandstone at Conway River mouth. These may indicate either 1) contamination by bioturbation from the overlying Teredo Limestone; or 2) that the Claverley Sandstone extends into the Teurian at that location.

Facies Interpretation

The depositional environment inferred by Warren & Speden (1978) is based mainly on the assumption that the Claverley Sandstone and the Teredo Limestone are part of the same Formation. This premise has led not only to a gross error in estimated sedimentation rates but also to an inferred environment that encompasses aspects of both units.

A shallow water environment is suggested by the limited microfaunal analyses. The notes for P31/f70 indicate a shallow water, paralic setting in the Seymour Stream area. The presence of algal boring in phosphatic clasts (see Chapter 6.1) suggests accumulation within the photic zone. Paleobathymetric data for the bounding Formations in most cases suggest an inner shelf environment. There is no evidence to indicate that water depths for the Claverley Sandstone were significantly different.

Deposition in high energy, well oxygenated bottom waters is indicated by good sorting, a generally low pyrite and organic carbon content, and a very active infaunal community.

The paucity of preserved primary sedimentary structures inhibits an understanding of the paleoenvironment. Where bedding is present, it is often transitional into the overlying Mead Hill Formation or defined by coarse, basal layers. These relationships suggest an early phase of sedimentation under winnowing and erosive influences which in some areas was followed by a low-energy regime, perhaps similar to that of the Mead Hill Formation (see Chapter 4.1), during the latter part of deposition.

Variations in thickness between outcrops can be related to three factors:

1. Original depositional patterns.

Primary variations in thickness can be demonstrated between Bluff River and Branch Stream (Figure A1). Conformable sedimentary contacts suggest that erosion of the upper surface did not occur in these sections. Greater thicknesses may have accumulated in broad (km-scale), gentle depressions on the surface of the underlying Woolshed Formation. The other alternative is that the Claverley Sandstone was deposited on a planar surface in a series of equally broad hummocks and swales.

2. Erosion beneath the sub-Teredo Limestone unconformity (see Chapter 4.2).

At least some of the lateral variation in the thickness of the Formation between Haumuri Bluff and Conway River (see Fig.18 in Warren & Speden 1978) can be attributed to erosional irregularities in the upper surface. In extreme cases (e.g. Limestone Hill and Monkey Face), the Claverley Sandstone (and the overlying Mead Hill Formation) has been completely removed in this way, resulting in Teredo Limestone resting unconformably on Woolshed Formation (e.g. Figure 4.2.10).

3. Post-depositional remobilization and expulsion.

In several locations, there is clear evidence that tectonic attenuation has occurred as a result of both intra- and inter-formational sediment transfer. In Bluff Stream, the Claverley Sandstone wedges out laterally, over a distance of 75m from a maximum thickness of c.30m. Because both the upper and lower contacts are concordant and lack onlap relationships, it is unlikely that this thinning was a primary depositional feature. Local pinch-and-swell structures, superimposed on the general thinning trend, have produced 1-2cm wide sandstone dikes which penetrate upwards into the Mead Hill Formation.

A similar situation is exposed on the shore platform on the south side of Kaikoura Peninsula where the Claverley Sandstone has been completely removed and the Mead Hill Formation directly overlies the Woolshed Formation (Figure B1). In both examples, the Claverley Sandstone has been expelled upwards from its original stratigraphic position via high angle clastic dikes.

In Wharekiri Stream, thinning has occurred by downward expulsion of sediment through low angle dikes and sills which extend to a depth of several metres into the underlying Woolshed Formation.

The interpretation by Warren & Speden (1978), that the sediment represents the accumulation of wind-blown detritus is based on two assumptions. Firstly, the sediment has a finely skewed, poorly sorted grain size distribution which they argue is typical of loess deposits. That assumption may be true at Haumuri Bluff, but it is not the case elsewhere in Marlborough, where the sediment is clearly well sorted (Chapter 6.1). Secondly, by assuming continuous deposition from the base of the Claverley Sandstone to the top of the Teredo Limestone, they assumed that the Formation accumulated over a lengthy period (c.10m.y.). They rationalized that a process involving slow deposition of wind transported sediment could account for the relatively thin sequence.

Because a major unconformity separates the two units at Haumuri Bluff, it is likely that their estimation is at least an order of magnitude too high. Additionally, the presence of a limited but significant quantity of coarse sand to granular size detritus cannot be explained by wind deposition.

It is difficult to determine sediment accumulation rates for the Claverley Sandstone in the manner of Warren & Speden (1978), because the duration of sedimentation cannot be gauged accurately. However, the presence of intense bioturbation, scattered phosphatic clasts and ubiquitous glauconite indicates slow rates of accumulation.

The burrowed base of the dolomite concretion-bearing interval of Claverley Sandstone at Kaikoura suggests a period of non-deposition prior to accumulation. Furthermore, the bored and phosphatized outer surface of the concretions indicates a history of reworking from the underlying sequence, analogous to that described by Hallam (1969). It is unlikely that the concretions have undergone significant transportation, as suggested by Browne (1985), because they are all intact.

It is more probable that erosion of the enclosing siltstones (Woolshed Formation) produced a residual, in situ, coarse lag of glauconitic, detrital and concretionary debris (see Chapter 6.1). Because there is no evidence of subaerial exposure at that location, it is likely that erosion was caused by the winnowing effect of submarine currents. Such a process has been suggested for phosphate deposits within the European Chalk (Jarvis 1980), and would induce opportunistic organisms to bore into the concretions which would have provided hard, stable substrates. Current velocity was occasionally high enough to roll the exhumed concretions on the sea floor and allow exposure of the entire surface.

Although the breccia in Wharekiri Stream might be related to possible disruption induced by the downward expulsion of sediment in the underlying sills, such an explanation fails to account for the presence of the exotic, rounded pebbles. It is more probable that the breccia represents a basal lag, and that the large blocks of Woolshed Formation are derived from considerable erosion into that unit. This interpretation is reinforced by the anomalously thin sequence (<20m) of Woolshed Formation beneath the Claverley Sandstone at this location, and by the intensity of bioturbation on the lower surface. This explanation is equally tenable for the examples cited at Bluff Stream and Kaikoura, although there is no prima facie evidence that significant erosion into the Woolshed Formation actually occurred at either location.

The most northerly outcrop of Claverley Sandstone (at Branch Stream), which must be close to where the unit pinches out, is the only locality where highly carbonaceous deposits occur. The uppermost, anomalously thick, carbonaceous layer is probably faulted against the base of the Mead Hill Formation, and it is possible that a much thicker deposit was originally present which acted as a convenient tectonic slide surface. The carbonaceous material is unlikely to have been derived from the dominant paleoshoreline which lay at least 75km to the south (Wilson 1956; Stevens & Suggate 1978) and an unknown, but probably considerable, distance to the west. A more local source could have been a nearby emergent island or lagoon, a possibility that is reinforced by the regressive, shallow water nature of the facies.

Paleoenvironmental and petrographic data, facies relations, together with the widespread distribution of the Claverley Sandstone suggest that it was deposited on a relatively shallow, very broad, sediment-starved shelf. Water depths and shelf gradients, although probably not greatly different from those of either the Woolshed or Mead Hill Formations, may have been low enough to allow very localized subaerial exposure at large distances offshore.

The Claverley Sandstone represents a very distinct facies separating two very fine-grained units: one carbonate (Mead Hill Formation) and the other non-carbonate (Woolshed Formation). An understanding of the nature of the upper and lower stratigraphic contacts with these units is essential to a facies reconstruction. Age constraints are of little help as the boundaries of the unit are isochronous at the resolution of the method of dating.

A widespread period of erosion in late Haumurian times immediately preceded the Claverley Sandstone and heralded the cessation of siliciclastic sedimentation in eastern Marlborough. Three possible models are presented to account for this break in deposition and subsequent accumulation of a distinctly coarser facies.

1. The unit may represent a transgressive facies which migrated southward. This alternative can be immediately eliminated because the

Formation pinches out to the north. In addition, a transgression could not account for the underlying hiatus or the indications of shallowing upwards.

2. The Claverley Sandstone may have built out as a progradational shelf wedge from the south. This possibility can be discarded because of the large distances over which the unit would have had to prograde in a relatively short span of time. It would be difficult to understand how progradational outbuilding could produce the relatively thin (c.50cm) deposits present near Muzzle Stream.

3. It is more probable that the Claverley Sandstone represents a regressive facies, produced either by in situ erosion of the underlying Woolshed or by a northward migrating sand belt. The period of non-deposition, (bio)erosion and possible emergence suggests a positive change in the base level of sedimentation. There is no evidence that this change was associated with a eustatic sea-level fluctuation (Vail et al. 1977). The regression was obviously minor, representing a brief deviation from the overall transgressive regime that was reinstated with the initiation and very rapid transgression of Mead Hill Formation over the Claverley Sandstone.

Localized differential erosion of the Woolshed Formation is attributed to minor tectonism. Although submarine currents are likely to have caused erosion, it is unlikely that they could account for c.200m of local stripping on a horizontal sea floor. Uplift associated with (compressional?) tectonic activity may have produced bathymetric highs on the sea floor which were preferentially eroded. Clastic dikes in the underlying Woolshed Formation, which do not penetrate the Claverley Sandstone, were probably emplaced during this period of tectonism. If these dikes extruded onto the sea floor, they would have provided sediment for reworking (see Chapter 6.1). Tectonism is inferred to have been the main control on regression and unconformity development beneath the Claverley Sandstone.

Chapter Four

AMURI LIMESTONE STRATIGRAPHY

4.1 Mead Hill Formation

Name And Definition

Webb (1966) first introduced the name Mead Hill Formation (MHF) to describe those rocks in the eastern Marlborough area, containing microfossils belonging to the Haumurian *Globotruncana circumnodifer* foraminiferal assemblage zone. The name is derived from the peak which forms the south wall of the gorge in Mead Stream. Webb (1966, p.59) described the unit at that location as consisting of "*800 feet ... of greensands, interbedded greensands and flint, and bedded flint, and flint and then interbedded limestone*".

The MHF is defined in this thesis as dcm-m thick, greenish grey, very well indurated, muddy, foraminiferal, micritic limestones interbedded with mm-cm thick, medium dark grey, poorly indurated, calcareous, smectite mudstones or marls. The occurrence of dolomite or chert, although extensive in many areas, is not necessarily a defining characteristic.

The Lower Chert and Flaxbourne Limestone are both Members of the Mead Hill Formation.

Synonomy

The synonomy of the MHF is detailed by Webb (1966 p.57-58). According to that author, no fewer than 15 various names had been used to describe the Formation (e.g. Figure 2.2.1). However, most of these names were erected to include units not within the present definition of the MHF.

The Formation was first described as "*Flint Beds*" by McKay (1877a), from exposures in the Hapuka River (=Puhi Puhi River), and he later (McKay 1885) stratigraphically separated it from the Amuri Limestone. This name has tended to be the most commonly applied, and its usage continued after the publication of the term "Mead Hill Formation" by Webb (1966). MacPherson (1948, 1952) referred to the MHF in the Kekerengu River area, as the "Chert Member" of his "Amuri Limestone Group". Lensen (1962) used the nomenclature "*flint beds, greensand with flint*" and

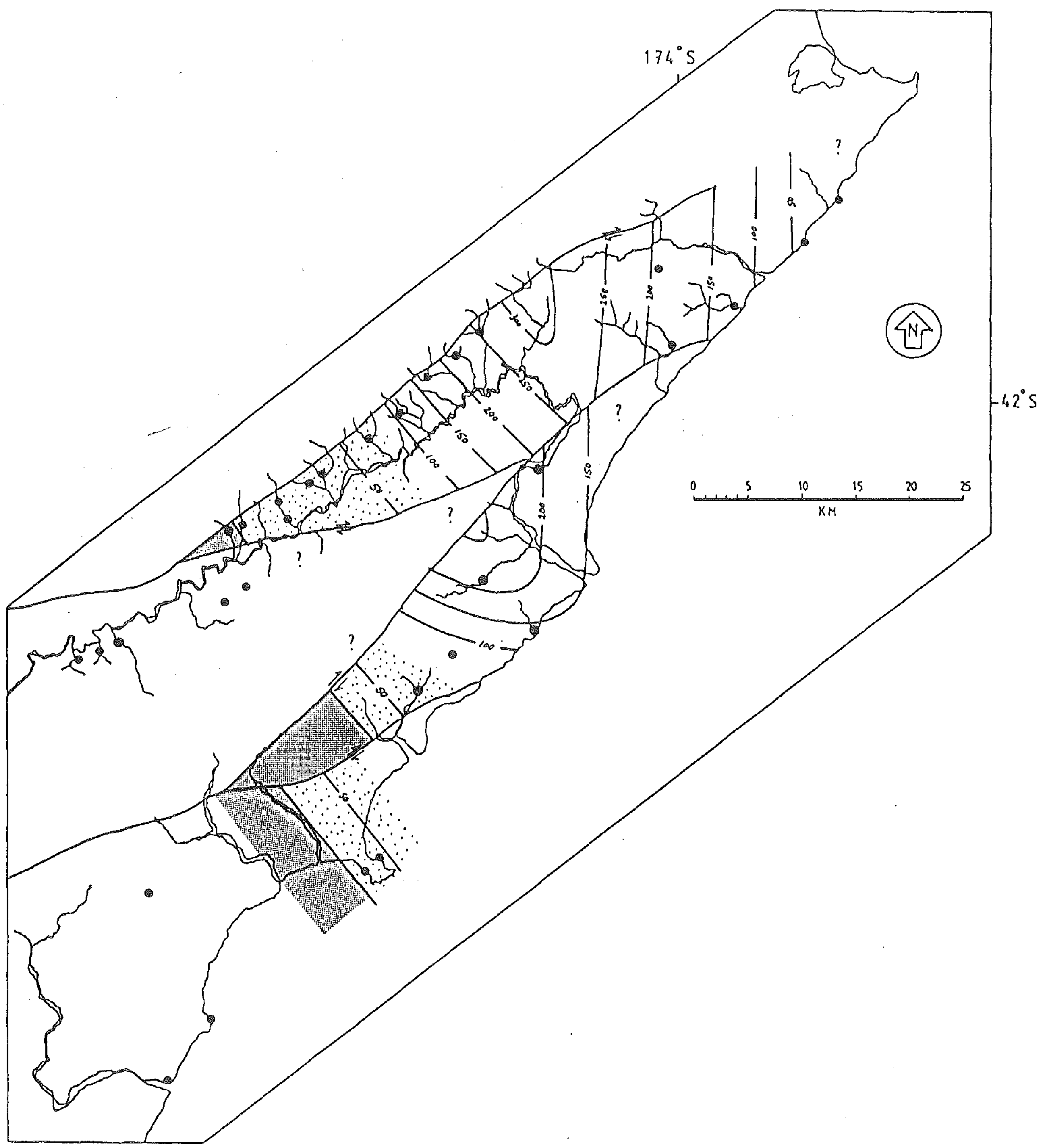


Figure 4.1.1: Paleoisopach map for the Mead Hill Formation. Contours in metres.
Shaded areas = total erosion or non-deposition
Stippled areas = partial erosion of upper surface
Solid circles = measured sections

later (Lensen 1978a) modified Webb's earlier usage by altering the name to Mead Hill Flint.

Previously, the unit has either been considered as an integral member of the Amuri Limestone (e.g. Hall 1964; Prebble 1976; Fergusson 1984) or as a Formation separate from the rest of the Amuri (e.g. Webb 1966; Lensen 1978a).

Distribution And Thickness

The MHF outcrops along a thin NE-trending inland strip several km west of the Clarence River between Bluff River in the south, and Ben More in the north. Near Ben More, the belt widens and bends through 180°. The outcrop pattern in near coastal regions is less continuous and the unit is absent south of Kaikoura Peninsula (Figure 4.1.1).

The maximum recorded thickness for the Formation is 280m in Mead Stream. Paleoisopach patterns suggest that the unit attains its maximum thickness (>300m) approximately 5km NE, in the vicinity of Swale Stream (Figure 4.1.1). An impassable gorge at that location prevents verification.

From Swale Stream, the MHF rapidly thins both to the SW and NE at an average rate of 12m/km. Isopachs are more widely spaced to the SW of Branch Stream, where the Formation is capped by an erosional upper surface (see Figure 4.1.1: stippled regions). Pre-unconformity depositional thicknesses were probably very regular in the SW, and the isopach spacing largely reflects the effects of erosional truncation. Closer to the depocentre, where there has been little significant erosion of the upper surface, original depositional thicknesses coincide more closely with the isopachs.

The situation NE of the depocentre is not so well defined. The MHF wedges, but the rate of thinning is less variable than in the south. No unequivocal evidence of truncation was detected, but the burrowed sequence which caps the unit from Woodside Creek north may eventually pass into an unconformity (see Chapter 4.2). The overall pre-erosion isopach pattern initially suggests deposition in a symmetrical, NW-trending, trough shaped basin with a depocentre near Swale Stream.

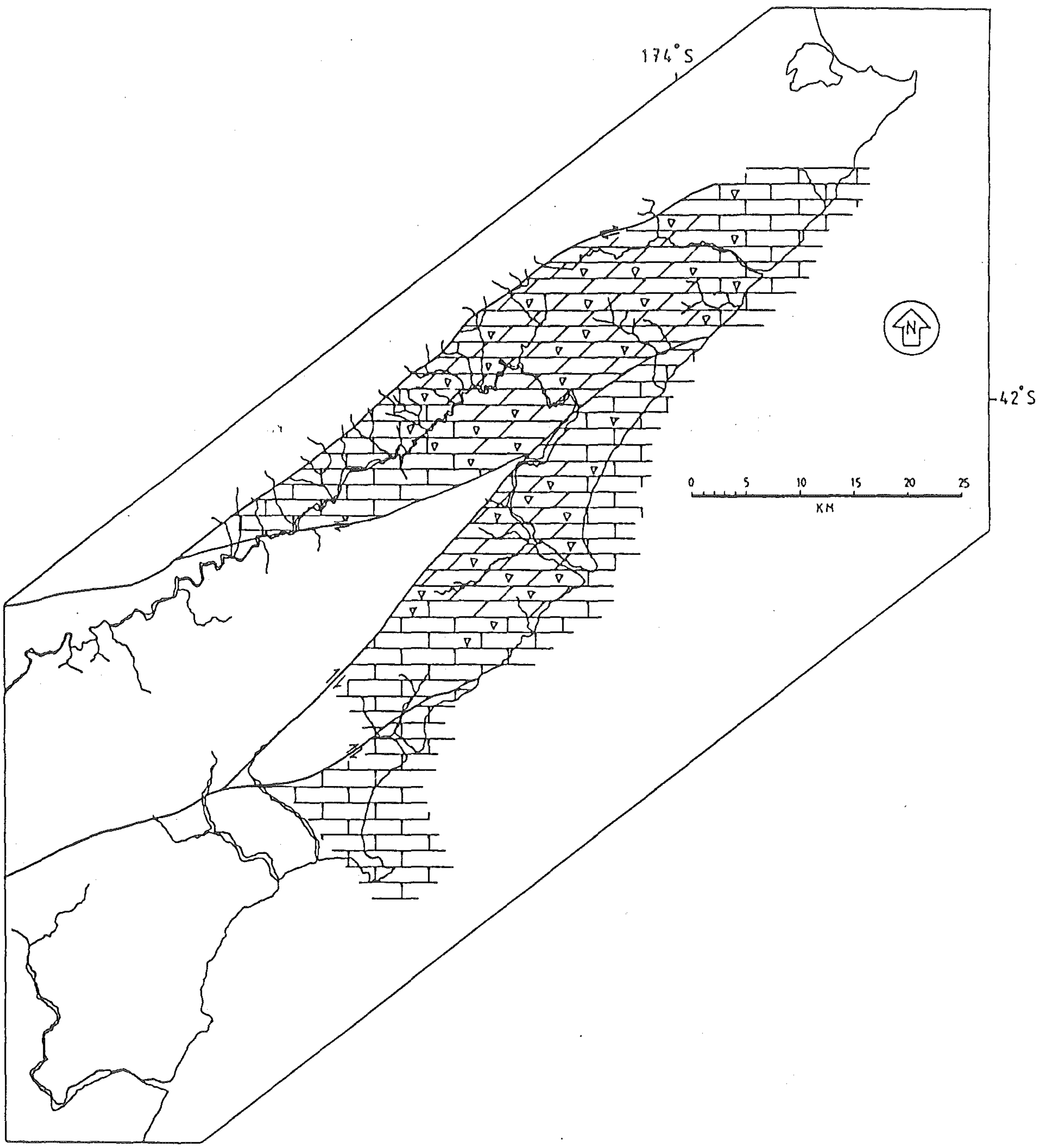


Figure 4.1.2: Diagenetic facies map for the Mead Hill Formation outlining the distribution of chert and dolomite.

Relation To Underlying Rocks

The MHF rests conformably on the Upper Iwitahi Group. The Formation overlies Claverley Sandstone to the south, and Woolshed Formation to the north of Branch Stream (see Chapter 3).

Although typically sharp, the basal contact of the MHF is locally gradational over several metres. In several locations, where the Formation gradationally overlies Claverley Sandstone, the transition may be a later diagenetic effect due to chertification extending down from the base of the MHF (e.g. Appendix IV: JM 25). In other examples, where the gradation is more likely to be a primary depositional feature (e.g. Wharekiri Stream), the Claverley Sandstone becomes progressively more calcareous upwards, as the composition changes from sandstone to micritic sandstone to sandy micrite to micrite. Correspondingly, a style of bedding akin to that in the overlying MHF becomes prominent in the upper part of the Claverley Sandstone (Figure 3.2.7).

Outcrops displaying the basal contact of MHF on Woolshed Formation are less numerous. Field observations generally indicate that the surface is sharp, although it is possible that diagenetic enhancement has occurred. In several instances (e.g. Isolation Creek), the uppermost Woolshed Formation is highly siliceous and dolomitic, whereas the overlying MHF is anomalously rich in detrital clays and silt. At Isolation Creek, the actual contact has been replaced by a 50cm zone of coarsely crystalline dolomite (Figure 4.1.9).

At Kaikoura (Appendix IV: JM 1) and lower Bluff Stream (Appendix IV: JM 50A), the MHF rests with a sharp, concordant contact on Woolshed Formation. This relationship is a special case, resulting from the removal of the entire Claverley Sandstone, plus an indeterminate thickness of Woolshed Formation, upward via clastic dikes which cut the MHF and feed the overlying Teredo Limestone (see Chapter 4.2). The contact is termed a *"hybrid-conformity"* (new name) and is due to the tectonic superimposition of a conformity (MHF/Claverley) on an unconformity (Claverley/Woolshed).

Nowhere has evidence been found to suggest that the boundary between the MHF and either the Claverley Sandstone or Woolshed Formation is unconformable. Features such as concentrations of *Thallasinoides* burrows, glauconite or phosphatized nodules, which are elsewhere in the succession typical of sedimentation breaks, are absent.

Type Section

Mead Hill Formation

Although Webb (1966, 1971) provided several reference sections and suggested Mead Hill as the type locality for the Formation, a formal type section was not designated. Defining a suitable stratotype for the MHF presents a problem in that the stratotype should be representative of the unit as a whole and display continuous exposure between the basal and upper contacts. Because no section fully satisfies these conditions, a composite-stratotype must be constructed.

The upper limit of the MHF is always marked by an unconformity (see Chapter 4.2) and therefore, at least part of the Formation is often missing (see also Webb 1966 p.59). A necessary condition for the type section then, should be a minimum amount of erosional truncation on the upper surface. The Mead Stream section (Appendix IV: JM 30) between S35/087451 and S35/075452, is selected as the upper component-stratotype. At that location, the MHF extends 280m above the faulted contact with Early Cretaceous (Motuan) age Split Rock Formation sandstones. The upper boundary coincides with the base of the Upper Chert Member of the Lower Limestone Formation. Although the upper surface coincides with a significant lithologic change, there is no evidence that the contact is erosional.

The Formation, as it is represented in Mead Stream, consists of nodular-bedded (10-20 cm scale), greenish grey, very well indurated, foraminiferal biomicrites interbedded with mm thick marls. Limestones are highly silicified and there has been considerable replacement by nodular chert and by both massive and disseminated dolomite.

The lower component-stratotype (essentially the lower boundary-stratotype) is represented by the basal contact of MHF on Claverley Sandstone outcropping in Dart Stream at S42/973340 (Appendix IV: JM 42). Dcm-bedded, light grey, well indurated, foraminiferal biomicrites interbedded with 5-10mm marls rest sharply, but conformably on massive, non-calcareous, fine sandstone (Figure 3.2.8). This section has several shortcomings including: 1) relative distance (14.5km) from the upper component-stratotype; 2) the Formation overlies Claverley Sandstone rather than Woolshed Formation (as inferred at Mead Stream); 3) the age of the lowermost limestones is probably much younger than at Mead Stream (see Figure A2); 4) chert and dolomite are poorly developed.

a) *Lower Chert Member*

The base of the stratotype for the Lower Chert Member (LCM) at Mead Stream (Appendix IV: JM 30) corresponds to the abrupt appearance of interbedded 10cm thick, rusty weathering, moderately (25%) dolomitic, silty, non-calcareous chert and mm thick, non-calcareous, pyritic mudstones at (O30/083448). These overlie interbedded dcm thick, very well indurated, non-dolomitic, moderately (25%) cherty, micritic limestones and 5-10mm marls. The section extends up 24.4m to the abrupt contact with the overlying interbedded 20cm thick, moderately dolomitic, slightly (<10%) cherty, micritic limestones and interbedded mm thick marls. The unit is poorly dated but is probably uppermost Haumurian.

b) *Flaxbourne Limestone Member*

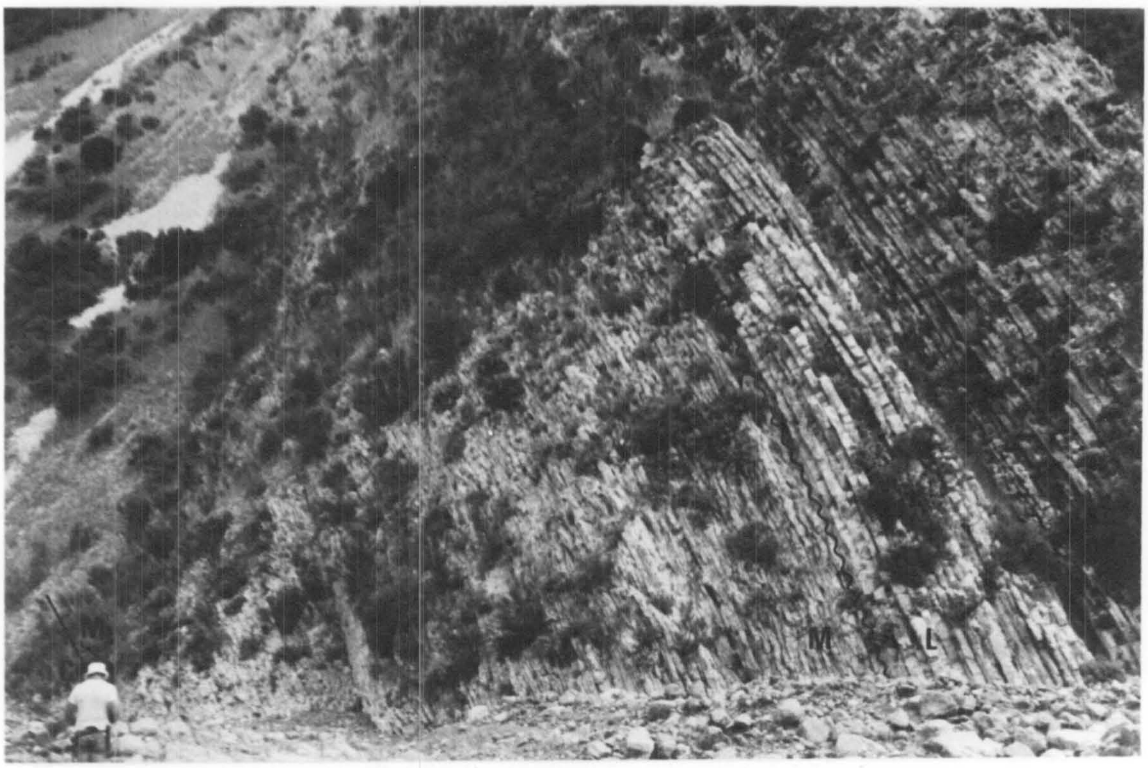
The Flaxbourne Limestone Member (FLM) outcrops in the vicinity of Chancet Rocks and Needles Point (Price 1974), and is well exposed in the type section at the mouth of the Flaxbourne River (S36/436574). The unit is intercalated within the Woolshed Formation and separated stratigraphically from the rest of the MHF by approximately 200m. The lithologic characteristics of the FLM are very similar to those of the rest of the MHF in the area. There is no significant variation in either lithology (e.g. bedding, petrography, chert, dolomite, ichnofabric, etc.) or the thickness (c.20m) of the unit over its known extent. Several thin (5cm) sandstones are intercalated near the base of the Member. Chert nodules are relatively common throughout but dolomite is absent. Age determinations from the FLM and from the enclosing Woolshed Formation suggest a mid to late Haumurian age (S36/f1003, f1017).

The basal contact of the FLM with the lower part of the Woolshed Formation (Mirza Formation of Price 1974) is sharp but apparently conformable. Intensive clastic sill intrusion has disrupted the immediately underlying sediments (Lewis & Laird 1980). The upper contact is also sharp, but is intensely burrowed by *Chondrites*, which extend c.10cm into the uppermost limestones (Figure 4.1.16). These burrows are infilled with sediment from the overlying unit.

Prebble (1976) correlated his *Wharanui Point Limestone* with the FLM. Further investigation of the type section cited by Prebble reveals that the stratigraphic sequence there is overturned and that the Wharanui Point Limestone is probably continuous with the rest of the MHF.

Figure 4.1.4: Nodular-bedded, chert-poor facies of the Mead Hill Formation (M) conformably overlying Claverley Sandstone (C), and unconformably overlain by Teredo Limestone and well-bedded Lower Limestone (L). Muzzle Stream (S42/923301).

Figure 4.1.5: Nodular-bedded, chert-rich facies of the Mead Hill Formation. Mead Stream (S35/087452).



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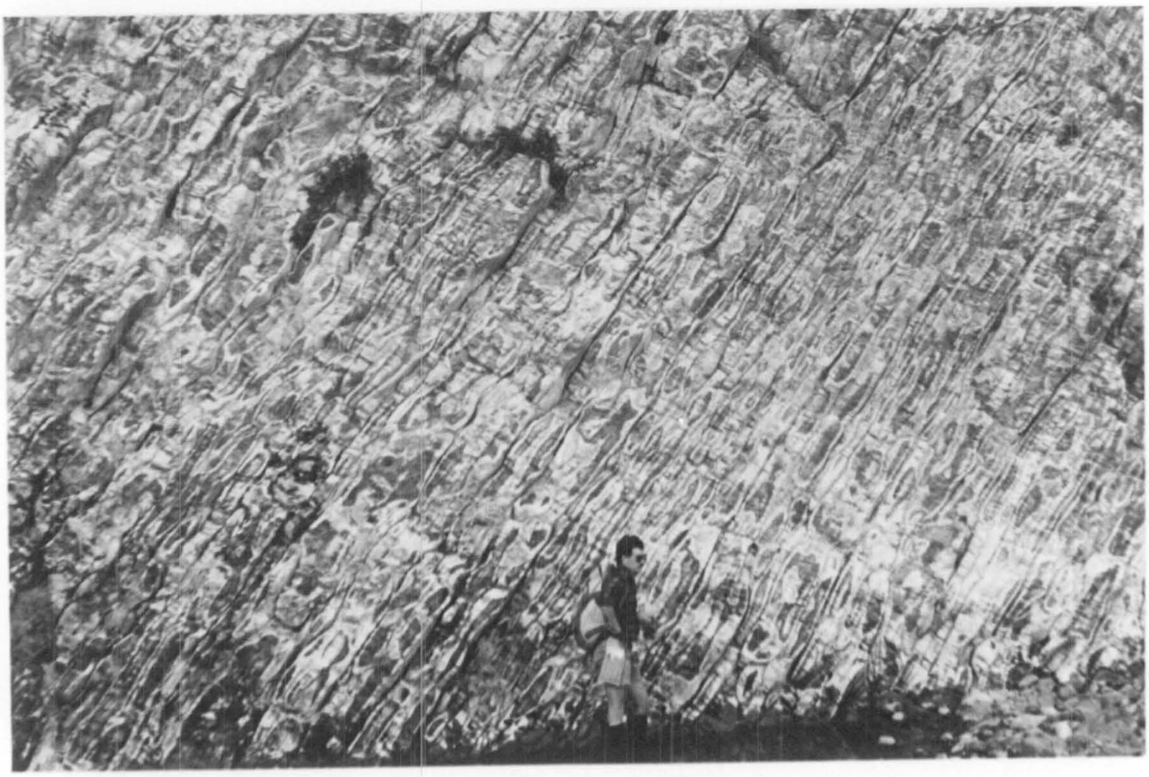


4.1.5

Reference Sections

The stratotype of the MHF in Mead Stream displays features characteristic of the unit where it is present as part of a relatively thick sequence (i.e. >200m). However, the occurrence of chert and dolomite, in particular, is atypical of the unit in thinner sequences and several further reference sections are necessary to demonstrate MHF variability.

1. *Muzzle Stream* (S42/922299)

Approximately 24m of MHF are present in Muzzle Stream (Appendix IV: JM 43B). The Formation extends from a transitional basal contact with the Claverley Sandstone, up to the sharp, burrowed unconformity at the base of the Teredo Limestone (Figure 4.1.4). Minor quantities (<10%) of chert nodules up to 5cm thick are evenly distributed throughout and dolomite is completely absent. In terms of the style of bedding and composition, the limestones are similar to those seen in Mead Stream, except that average bed thickness (8cm) is much reduced. Several anomalous 10cm thick marl beds, one of which almost certainly corresponds to the Cretaceous/Tertiary (K/T) boundary layer (Strong 1987), are intercalated in the section.

2. *Woodside Creek* (S36/335478)

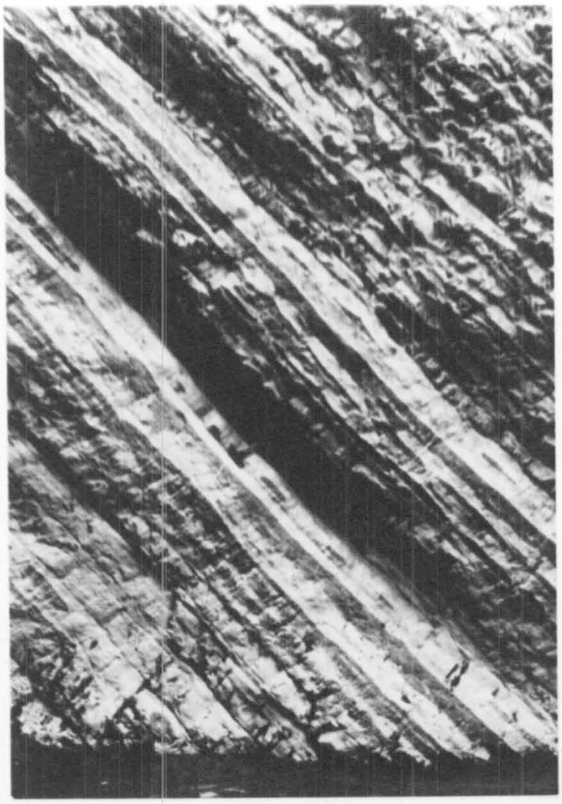
The main features of the MHF in the northern part of the study area are represented in the lower gorge in Woodside Creek. The base of the section extends from a stratigraphic position some 80m above the unexposed contact of the MHF on Woolshed Formation, and encompasses a paraconformity marking the K/T boundary. The 14m of section below the K/T boundary is characterized by 20-40cm thick, light greenish grey, very well indurated, slightly (15%) cherty, foraminiferal biomicrites interbedded with 1-10cm thick, softer marls (Figure 4.1.21). The lowermost 30m of Tertiary limestones are more thinly bedded (c.10cm) and richer in chert nodules. These grade up over 30m into less siliceous, more thickly (50-200cm) bedded, orange pink to reddish orange micritic limestones. The top of the Formation in the Woodside Creek section is poorly defined; neither field evidence nor biostratigraphic control is sufficient to accurately define an upper contact.

In contrast to more southerly outcrops, bedding planes are generally planar and show few signs of nodular distortion. However, the poorly exposed lowermost 80m of MHF below the reference section, contains abundant chert and dolomite and bedding planes are distorted.

Figure 4.1.7: Banded chert facies in Mead Hill Formation. Mead Stream (S35/085452). Hammer near centre for scale. *Photo: M. Lawrence.*

Figure 4.1.8: Interbedded chert (c) and dolomite (d) in Mead Formation. Mead Stream (S36/086451).

Figure 4.1.9: Contact between Mead Hill Formation (M) and Woolshed Formation (W). Isolation Creek (S36/254521).



4.1.7

4.1.8

4.1.9

Lithology

The MHF is composed of a sequence of "rhythmically" (Einsele 1982; Scholle et al. 1983) interbedded calcilutites and marls. Bed thicknesses are uniform in outcrop but regionally, decrease laterally in proportion to the overall Formation thickness. The average individual limestone bed thickness near the depocentre is approximately 30cm at the base, decreasing to 15cm near the top of the Formation. The southernmost and thinnest sequences of MHF have mean bed thicknesses of 10cm or less throughout. Interbedded marls are generally in the range of 1-5mm, although anomalous 10cm beds do occur.

Individual beds and sequences of beds can be traced for several hundreds of metres without appreciable variations in thickness. Unfortunately, lack of suitable marker horizons prevents the correlation of beds between widely spaced sections. The basal mudstone, which immediately overlies the K/T boundary, retains a constant thickness (c.10cm) throughout the entire study area (Strong 1987).

MHF calcilutites are almost devoid of any primary structures other than biogenic traces. No primary stratification, apart from rhythmic interbedding of marls and calcilutites (and very rare sandstones) was detected. Individual calcilutite/marl boundaries are non-gradational.

Features indicative of redeposition of calcilutites (e.g. grading, sole marks) were not observed. Penecontemporaneous slump structures such as slump folds, allochthonous slide packages, syn-sedimentary breccias are not present. Normally-graded foraminiferal calcarenites (<1cm thick) are rarely intercalated within calcilutites (Figure 4.1.11). Darker coloured silicified bands give the appearance of normal grading (e.g. Figure 4.1.19), but because there is no other change in lithology or ichnofabric it is likely that these are diagenetic features.

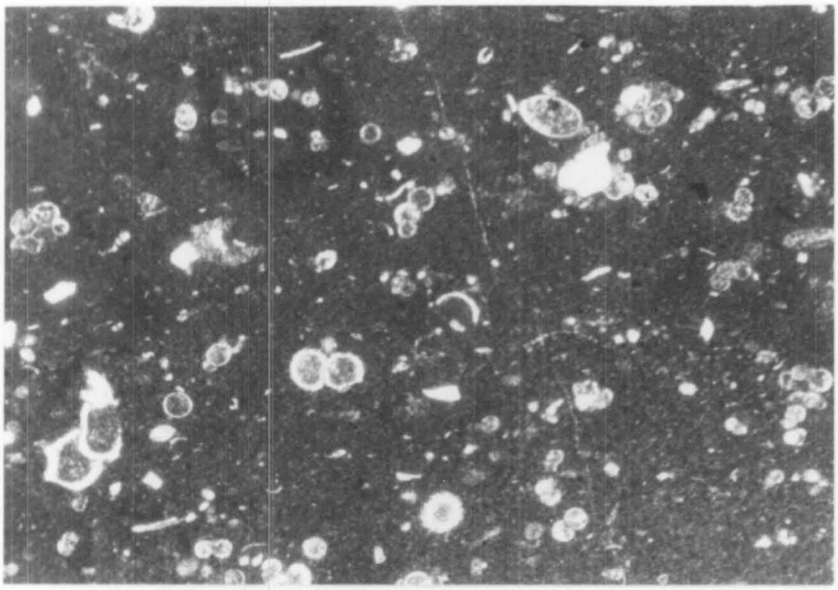
Nodular bedding (Figure 4.1:5), which is common in the MHF, and gives bedding planes a hummocky appearance, is attributed to post-depositional diagenetic effects (see also M. Lawrence, in prep.). Beds swell in harmony with the growth of internal chert nodules. It is assumed that the original bedding surfaces were more regular, in the style of the Formation where it contains less chert (e.g. Woodside Creek reference section).

Chert, which is present throughout the MHF in varying quantities

Figure 4.1.10: Thin section photomicrograph (uncrossed polarizers) of sparse foraminiferal biomicrite from Mead Hill Formation. Scale = 0.25mm.

Figure 4.1.11: Thin section photomicrograph (uncrossed polarizers) of normally graded foraminiferal calcarenite wackestone from Mead Hill Formation. Scale = 0.25mm.

Figure 4.1.12: Thin section photomicrograph (uncrossed polarizers) of replacement dolomite rhombs (d) in foraminiferal micrite from Mead Hill Formation. Scale = 0.25mm.



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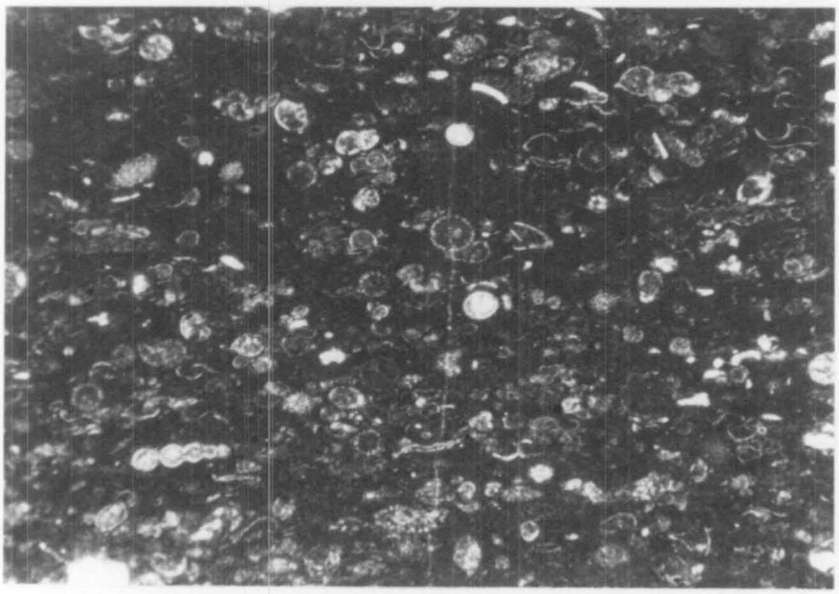

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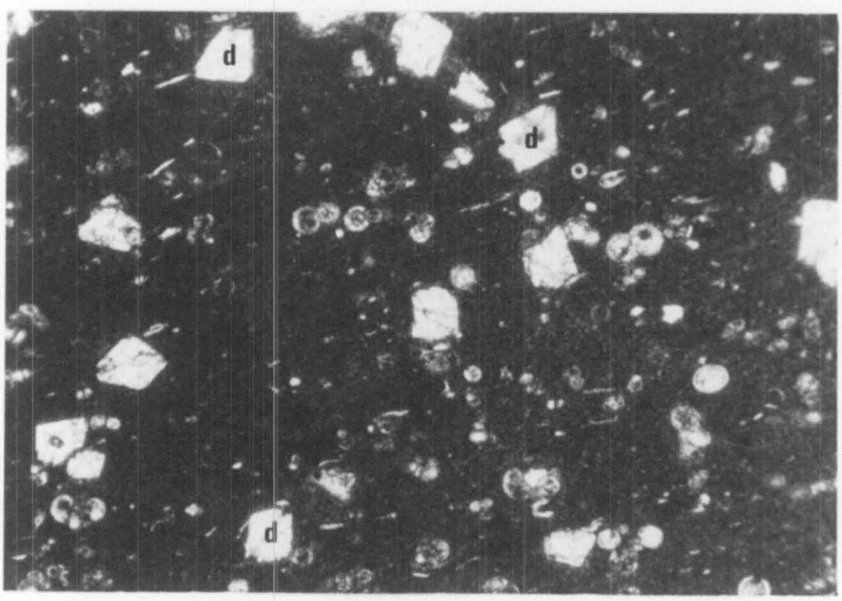


4.1.12

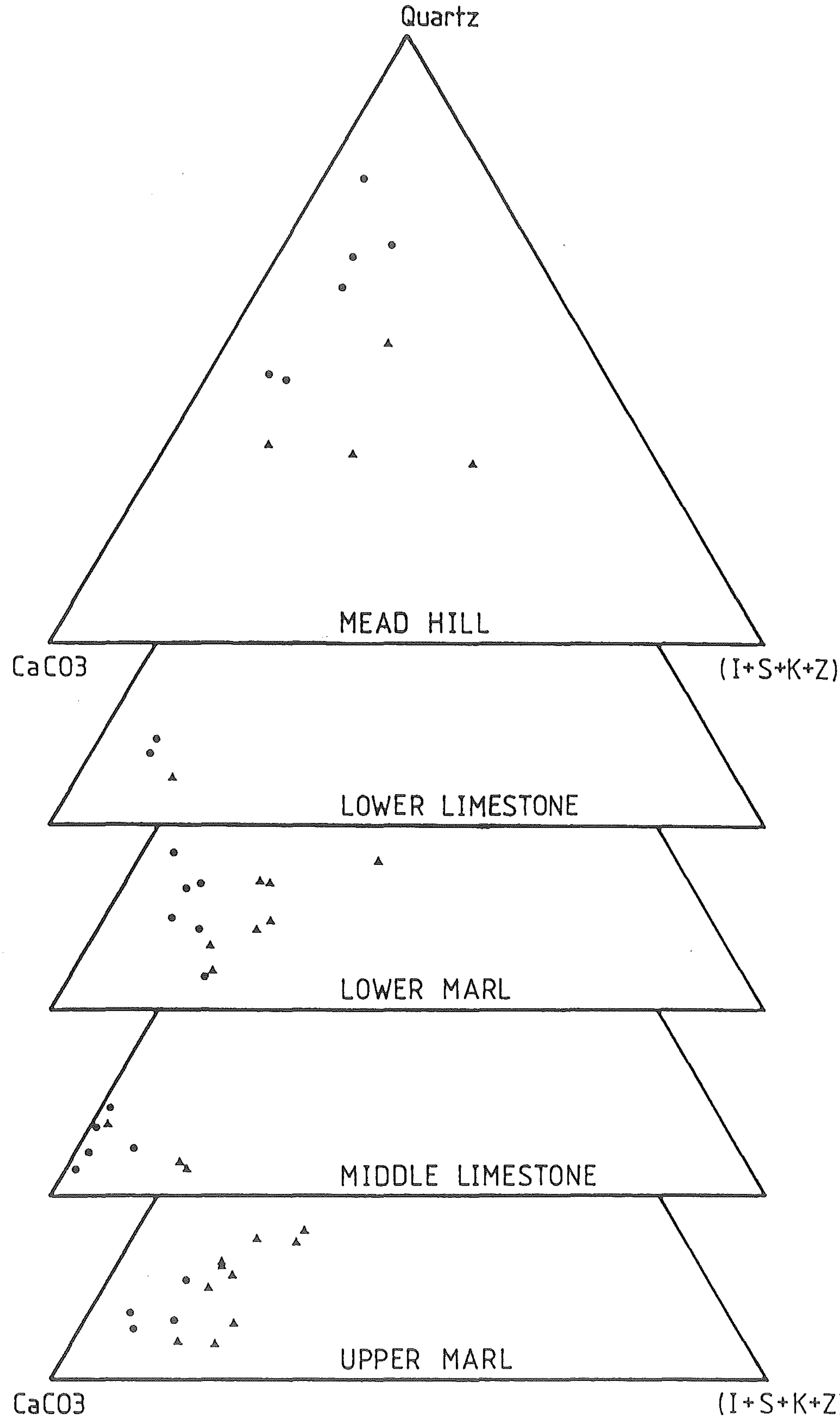
(5-95%), commonly occurs as circular (in plan), flattened, elliptical nodules. These nodules usually form in the centre of beds and can comprise over 90% of the host bed. At several horizons, nodules appear to have coalesced to form continuous bands which superficially resemble ribbon cherts (Figure 4.1.7). The surrounding limestone is almost always siliceous and is commonly non-calcareous.

Occurrence of chert is closely related to the thickness of the Formation. Limestone containing in excess of 30% chert is almost entirely confined to areas where the MHF exceeds 100m in thickness (Figure 4.1.2). In thinner sequences outside the 100m isopach, nodules are sporadic, less regular in shape, much smaller, and in many cases can be more accurately described as silicified limestone rather than chert. In general, the maximum volume of chert occurs in the lower half of the Formation (see also M. Lawrence in prep.).

Dolomite, which has a similar distribution to chert, is mostly restricted to areas thicker than the 150m isopach (Figure 4.1.2) and stratigraphically below the Lower Chert Member. Near the base of the Formation, in association with the maximum occurrence of chert, dolomite often replaces entire limestone beds (Figure 4.1.8). Higher in the sequence, massive dolomite gives way to partial replacement of only the silicified limestone rims surrounding nodular chert. In the uppermost 50m of its occurrence, dolomite is generally in the form of scattered rhombs floating in a limestone matrix (Figure 4.1.12). Scattered dolomite rhombs are frequently present within the chert nodules but their interrelationship is unclear. The interbedded "greensands" mentioned by several previous authors (e.g. Lensen 1962, 1978a; Webb 1966) are almost certainly a misidentification of dolomite.

Petrographic analysis shows that there is little variation in the primary calcilutite lithofacies throughout the MHF. Replacement by idiotopic dolomite rhombs and microcrystalline chert has obliterated primary textures in many samples. The sediment ranges in texture from a micrite to a sparse biomicrite (Figure 4.1.10). Well preserved foraminifera and radiolaria comprise up to 5% of the sediment. Robust benthic species predominate over delicate planktics in sequences thinner than 100m, whereas the reverse is true nearer the depocentre. Radiolaria, mostly spumellarian, are usually less well preserved and much less common than foraminifera (F:R > 10:1). Other biogenic constituents, excluding micrite, are extremely rare in thin section, although echinoid

Figure 4.1.13: Ternary diagrams showing composition of calcilutites (solid circles) and marls (solid triangles) from the Amuri Limestone Group. I+S+K+Z= total illite + smectite + kaolinite + zeolite.



spines are not uncommon in hand specimen. SEM studies confirm that micrite is composed of coccolithic debris; in most cases intense dissolution has obscured textures. No evidence of stylolitization was observed below the Lower Chert Member. Above that unit, within a 20m interval devoid of marl interbeds, bedding planes appear to have been modified to stylolitic seams (Appendix IV: JM 30).

Geochemical analysis was used to approximate the composition of the MHF calcilutites. XRD analysis enabled mineralogy to be determined qualitatively and recalculated XRF data helped to quantify results (Appendix II). The bulk of the sediment (>99%) can be described in terms of a 3 component system (Figure 4.1.13):

C = carbonate (micrite ± foraminifera)
Q = quartz (± cristobalite)
S = smectite

The high degree of induration of MHF calcilutite beds reflects the extent of silicification. The term "limestone" is slightly misleading, because whole rock carbonate values are relatively low (mean: 30.6%; minimum: 17.4%; maximum: 46.7%). XRF analysis shows that calcilutites contain an average of approximately 64% total SiO_2. Q values are correspondingly very high (mean: 59%; minimum: 43%; maximum: 77%). In general, calcilutites become less siliceous upwards and the uppermost beds are usually highly calcareous. An anomalous situation occurs at Woodside Creek, where the $CaCO_3$ content apparently decreases upwards across the K/T boundary (Brooks et al. 1986).

The high percentage of Q could not be resolved petrographically and it is therefore unknown whether it is present as clay-size detritus or as diagenetic, microcrystalline chert. The presence of abundant cristobalite in several samples, suggests that the latter is more likely. In any case, the mean ratio of Q:C is 1.9.

Smectite is the only clay mineral resolvable in XRD traces, and forms an average of c.10% of the whole rock (c.16% of the insoluble residue) composition of calcilutites.

Contrasting with MHF calcilutites, the interbedded, much less indurated marls average 37% C but only 36% Q. SiO_2 has a mean value of only 48%, indicating that a lesser amount of, if any, silicification has

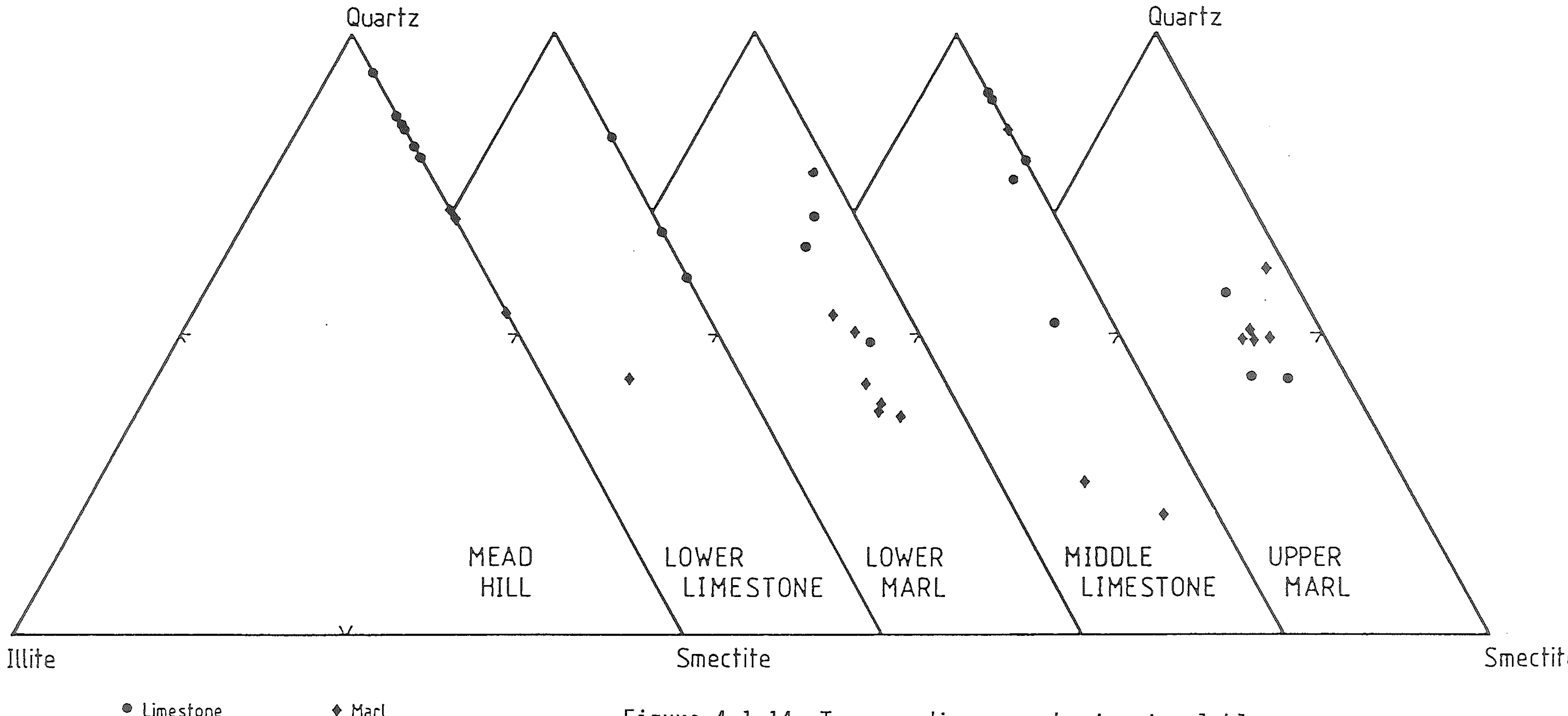


Figure 4.1.14: Ternary diagrams showing insoluble residue composition of calcilutites and marls from the Amuri Limestone Group. N.B. Only those samples with a non-carbonate fraction composed of quartz + smectite $\pm$ illite are shown.

occurred. No evidence of stylolytic dissolution was detected.

MHF marls differ from calcilutites not only in their whole rock carbonate and quartz content, but also in insoluble residue composition. The average non-carbonate composition of marls is 36%S/64%Q (c.f. calcilutites 16%S/84%Q).

Sand sized detritals are virtually absent from the MHF to the south of Woodside Creek, except near the base, where the unit overlies Claverley Sandstone and in Swale Stream where several anomalous 10cm sandstones were observed. Otherwise, the coarsest detrital grains occur in the Lower Chert Member, where coarse angular quartz silt is relatively abundant. Detrital silt is present throughout the MHF, although usually in amounts not exceeding a few percent. From Woodside Creek north, the MHF contains rare, intercalated sandstone beds both above and below the K/T boundary. These sandy beds become more numerous and thicker northwards and toward the base of the sequence. At Woodside Creek, several 1cm thick sandy horizons occur approximately 11m below the top of the Cretaceous sequence. These layers are internally structureless but have very flat bases and convoluted upper surfaces. *Thallasinoides* burrows extend several cm into the underlying limestone. At Needles Point (c.10km further north), possible correlatives of these beds are seen in approximately the same stratigraphic position in the MHF. Here, intercalated cross-laminated, normally graded, fine sandy, subfeldsarenites up to 10cm thick, are intercalated up to several metres below the K/T boundary.

Pyrite is a common component of calcilutites and forms as disseminated grains, cm-size nodules (Figure 4.1.18) and very rarely, as partial burrow replacement. The mineral does not generally exceed 0.1% of the sediment.

Paleontology

The MHF is almost barren of both benthic and pelagic macrofossils. Inoceramids, ammonites and belemnites, which are the dominant macrofossils in the underlying units are noticeably absent. An extensive search of the N.Z. Fossil Record File revealed that no previous macrofossil collection has been made. Three very poorly preserved molluscs were recovered from the unit during the course of this thesis. These include 2 small, indeterminate bivalves, one of which was derived from 1m above the base of the MHF at Bluff Stream, and the other from several metres above the K/T boundary at Muzzle Stream. Associated with the latter was an 8mm diameter gastropod tentatively identified as *Epitonium*? (J. Crampton, NZGS, pers. comm. 1986). The few macrofossils listed by Webb (1966) are from either the underlying Claverley Sandstone or the overlying Teredo Limestone.

Webb (1966, 1971) and Strong (1977, 1984, 1985, 1987) have been the main contributors to the micropaleontology of the Formation. Webb recognized two foraminiferal assemblage zones within the MHF. The base of the *Globotruncana circumnodifer* zone, which contains approximately 150 (arenaceous and calcareous) species, generally coincides with the base of the Formation and extends up to the K/T boundary. Foraminifera from the *G. circumnodifer* zone, extracted from the underlying Claverley Sandstone, led Webb (1966) to include that unit within the MHF. The *G. circumnodifer* zone is succeeded within the MHF by the *Globigerina triloculinoides* range zone (Webb 1966; Strong 1977). On the basis of the absence of foraminifera diagnostic of the intervening *Globigerina pauciloculata* zone (Strong 1977), the boundary is considered paraconformable.

Ichnology

Although the sediments are moderately bioturbated, ichnofossils are largely indeterminate in the MHF below the K/T boundary. The only recognizable trace fossils, apart from small *Thallasinoides* burrows associated with intercalated sandstones, are rare *Teichichnus* and indistinct, smeared-out *Planolites* (Figures 4.1.15 & 4.1.17). *Zoophycos* is entirely absent from MHF of Cretaceous age.

The level and diversity of bioturbation increases dramatically across the K/T boundary (Figures 4.1.18-20). *Zoophycos* appears in the sequence immediately above the K/T boundary at Woodside Creek. The lowermost appearance of *Zoophycos* in the MHF at Mead Stream, occurs just above the Lower Chert Member, where it is present intermittently in distinct 1-5m stratigraphic intervals. Within each interval, the density of *Zoophycos* can be as high as 20 spreiten-bands (2-5mm thick) per metre.

In the Mead Stream section, *Teichichnus* is relatively abundant within a 45m intensely bioturbated interval, which also encompasses several rich *Zoophycos* zones. Individual specimens of *Teichichnus* extend up to 20cm vertically and have a similar maximum width. Convex-downward oriented *Teichichnus* spreiten are more common than convex upward.

Figure 4.1.15: Section view of calcilutite from Mead Hill Formation of Cretaceous age. No recognizable ichnotaxa apart from smeared ?*Planolites*.

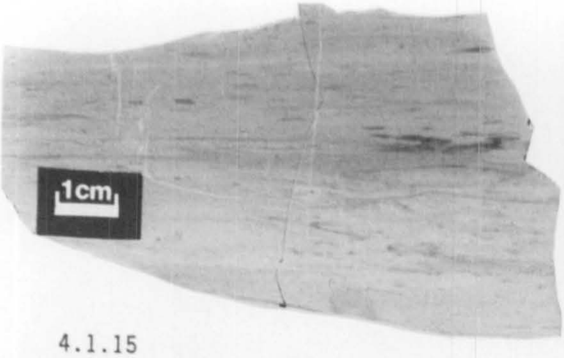
Figure 4.1.16: *Chondrites* exichnia penetrating into upper 10cm of Flaxbourne Limestone Member.

Figure 4.1.17: *Teichichnus* (T), *Planolites* (P) ichnoassemblage in calcilutite from Mead Hill Formation of Cretaceous age.

Figure 4.1.18: *Zoophycos* dominated ichnoassemblage in calcilutite from Mead Hill Formation of lower Paleocene age. Note pyrite nodule.

Figure 4.1.19: Sharp-rimmed, dark silicification band giving appearance of grading in Mead Hill Formation calcilutite. Note 1cm thick normally graded foraminiferal calcarenite near top (see Figure 4.1.11 for photomicrograph).

Figure 4.1.20: *Zoophycos* dominated ichnoassemblage in calcilutite from Mead Hill Formation of upper Paleocene age.



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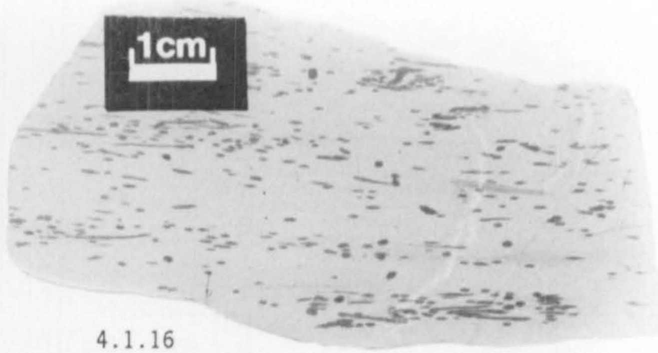

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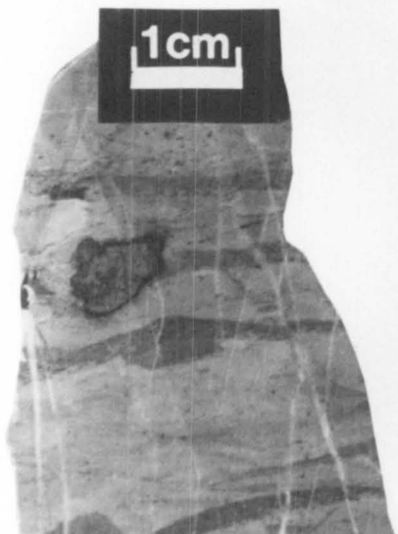

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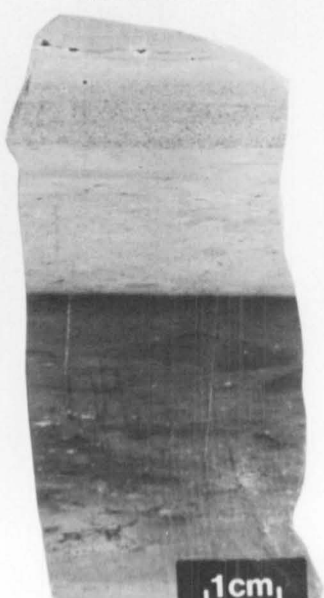

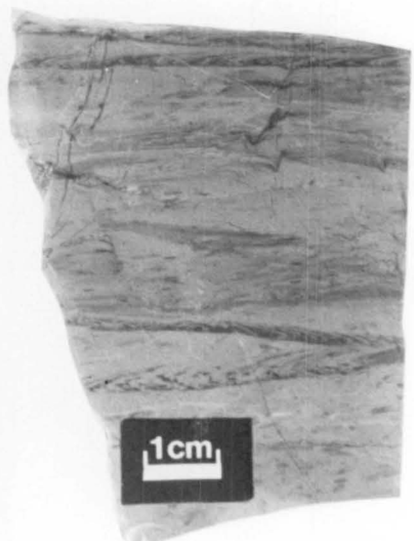

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Cross-cutting relationships consistently show that *Zoophycos* post-dates *Teichichnus*, indicating that the latter was the shallower burrower.

An anomalous horizon of silicified *Thallasinoides*-like, horizontal, branching burrows was observed in several sections near the base of the *Teichichnus* interval.

No definite examples of *Chondrites* were observed within the main body of the MHF. This ichnogenus is apparently restricted to the upper 10cm of the Flaxbourne Limestone Member (Figure 4.1.16).

Although correlation of individual *Zoophycos* zones between sections has not been attempted here, Figure A1 shows that packages of zones (c.50m thick) are probably laterally continuous over distances of at least 5km.

The K/T Boundary In The Mead Hill Formation

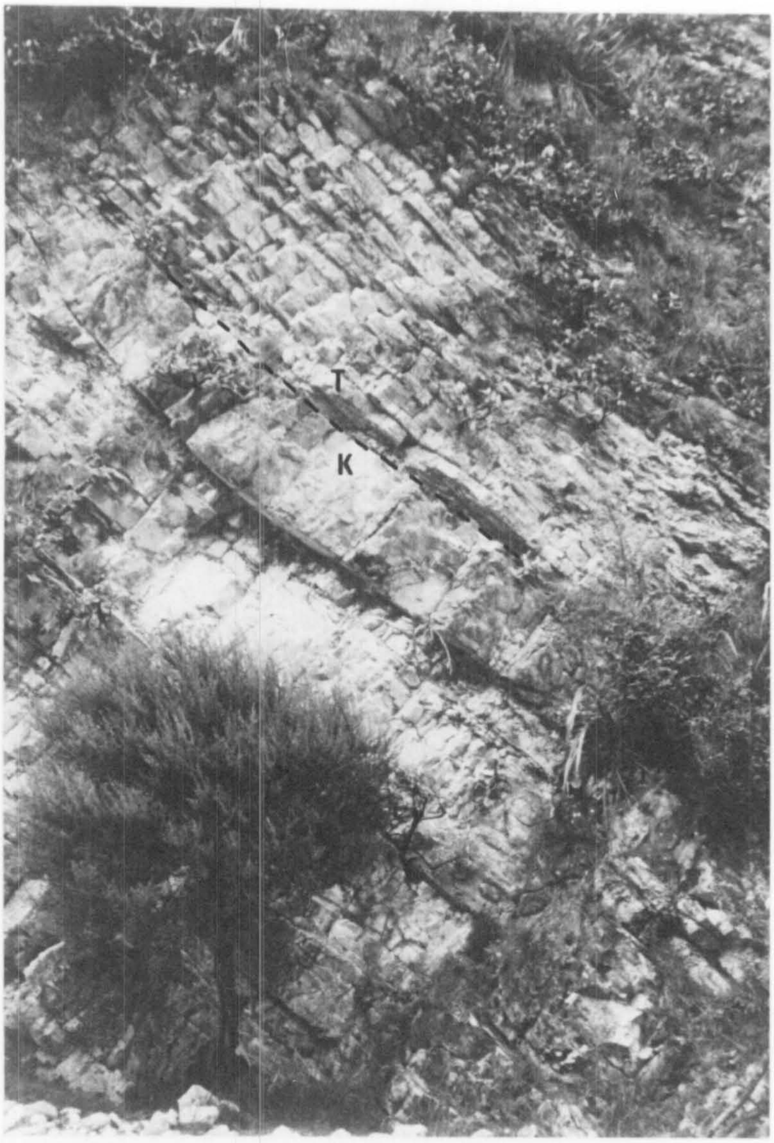
The stratigraphic position of the K/T boundary in the MHF at Woodside Creek (Figure 4.1.21) has been accurately described by Strong (1977). Several further sites at Chancet Rocks (Strong 1984) and at Needles Point (Strong 1985) have since been documented.

Paleontological results (Strong 1977, 1984, 1985) suggest a break in deposition across the boundary at Woodside Creek, Needles Point and Chancet Rocks, equivalent to at least one full foraminiferal (*Globigerina pauciloculata*) zone. Recent work (C.P. Strong, NZGS, pers. comm. 1987), indicates that the K/T boundary at Chancet Rocks may be less discontinuous than was originally thought, and a near complete faunal sequence may be represented at that location. Paleoenvironmental analysis suggests a marked shallowing from an upper "slope" (Haumurian) to an outer shelf (Teurian) facies at Woodside Creek, but a deepening trend from inner shelf (Haumurian) to mid shelf (Teurian) conditions at Kaikoura (Appendix I).

Several attempts at paleomagnetic correlation of the boundary sequence in the MHF, with the international polarity history have been unsuccessful because of the extremely weak natural remanant magnetizations (NRM's) of the limestones (J.A. Tarduno, Dept. Of Geophysics, Stanford University pers. comm. 1986). These intensities ($J < 3\times10^{-8}$) are close to the noise level of most cryogenic magnetometers. The low NRM's may suggest that the original magnetization has been altered

Figure 4.1.21: K/T boundary (dashed) in Mead Hill Formation. Woodside Creek (lower gorge) (S36/335478). Thinly (10cm) bedded Tertiary (T) overlying thickly bedded Cretaceous (K). Note lack of discordance.

Figure 4.1.22: Detailed view of K/T boundary paraconformity at Woodside Creek (S36/335478). K=uppermost Cretaceous; B=laminated "boundary layer"; T=Tertiary. Note paleomagnetic drill holes.



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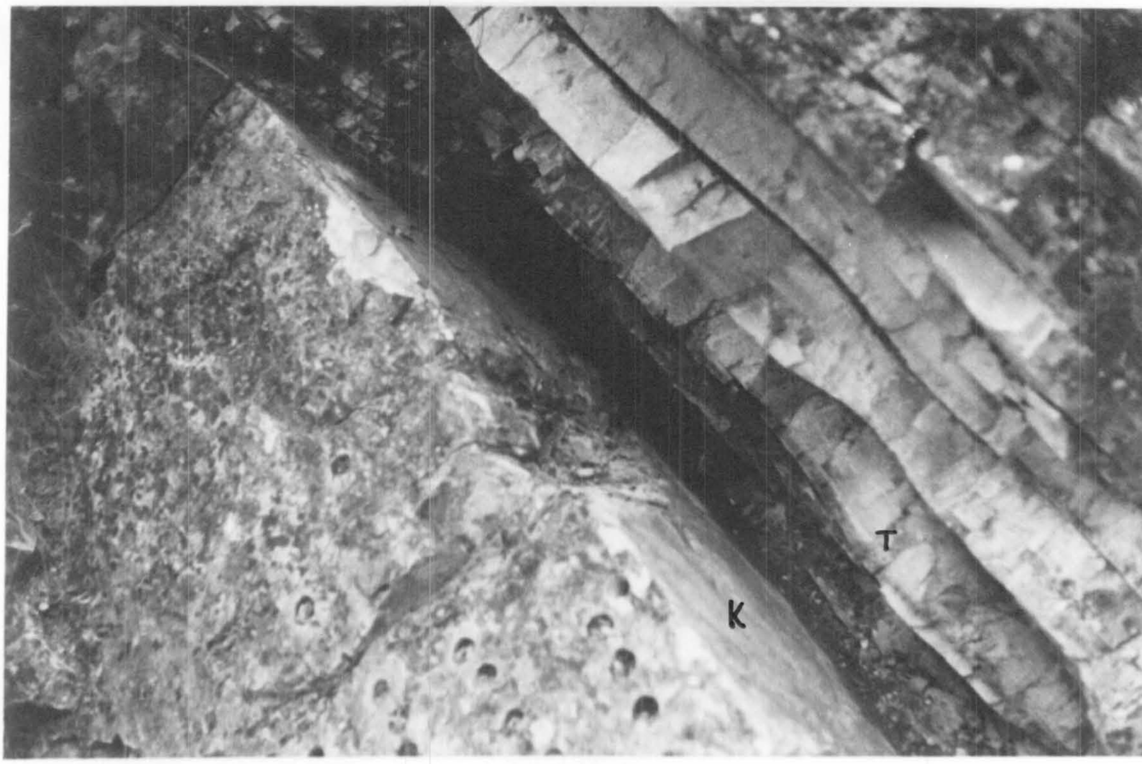


4.1.22

either tectonically, or by the dewatering effects of the underlying Woolshed Formation.

A detailed field investigation comparing the lithologies both above and below the boundary at Woodside Creek has shown that there are at least 7 distinct facies differences between the uppermost 10m of Cretaceous and lowermost 10m of Tertiary MHF (Table 4.1.1).

Table 4.1.1. Summary of lithofacies variations across the K/T boundary at Woodside Creek.

Characteristic	Cretaceous	Tertiary
Bed thickness (lst)	Variable c.20-40cm	Constant c.10cm
Max. bed thickness (lst)	140cm	20cm
Bed thickness (marl)	>1cm	<1cm
Colour (lst)	Light greenish grey	Greenish grey
Chert	Rare to absent	<10% Thin black bands
Internal structure (lst)	Massive	Basal 50cm laminated
Bioturbation	Not recognized	Zoophycos present

These marked lithologic changes correspond to the geochemical variations described by Brooks et al. (1984; 1985; 1986) from the same locality. According to those authors, the lowermost Tertiary rocks are generally much less calcareous than the underlying Cretaceous (mean wt%$CaCO_3$: Cretaceous = 65%; Tertiary = 41%). More striking, are the elemental anomalies, most notably that of iridium (boundary layer: 127ng/g; surrounding limestones: <0.1ng/g), associated with the boundary layer.

The boundary layer itself, which has been recognized in at least three separate locations without appreciable lateral variation, is lithologically distinct from the enclosing strata (Strong 1985). The lowermost Tertiary at Woodside Creek is represented by a c.10cm thick, dark grey to greenish black, poorly indurated, laminated, slightly calcareous, mudstone which has a rusty, limonite stained basal layer (Figure 4.1.22). The basal contact with the underlying Cretaceous, is concordant and apart from the overall lithologic and micropaleontological changes, there is little to suggest erosion or hardground formation as suggested by Brooks et al. (1986). The obvious signs that would indicate such a hiatus such as *Thallasinoides* burrows, scouring, or the presence of glauconite and/or phosphate are not apparent. The scouring described by Strong (1977), in the surface of the uppermost Cretaceous limestone, probably represents a secondary nodular distortion common in lower parts of the sequence.

Notwithstanding the lack of direct sedimentological evidence, it is apparent that a lengthy period of geologic time is not represented across the boundary in at least some areas. From the revised Paleogene time scale (Figure 1.2), the length of time from the end of the Cretaceous (66.5Ma) to the end of the missing *G. pauciloculata* zone (63Ma) is approximately 3.5 m.y. It is probable that at least this period of time would be needed to achieve the observed change in water depths, which are on the order of at least 100m (Strong 1977). The other lithofacies variations, which are all biogenically related, may be attributable to more rapidly acting processes. These processes, related to the causative K/T boundary event or driving force, are the subject of current debate and speculation (see Alvarez et al. 1980, 1984 and references therein). The probability that the K/T boundary in the MHF represents a lengthy paraconformity indicates that its usefulness as a depositionally continuous sequence for paleontological and paleomagnetic studies is limited.

Age

Because no diagnostic macrofauna were recovered, the age of the MHF is based exclusively on foraminiferal studies. The *G. circumnodifer* zone is correlated by Webb (1971) with the upper part of the Haumurian Stage (see also Figure 1.2). At each location, the relative age of the base of the MHF can be estimated from the thickness of the unit below the top of that zone (i.e. below the K/T boundary).

Near the depocentre (e.g. Mead Stream), where approximately 200m of lowermost MHF is of Cretaceous age, the unit probably represents most of the Haumurian Stage. However, this assumption is difficult to check, because the effects of intense diagenetic overprinting by chertification and dolomitization in these thicker sequences has largely destroyed most foraminifera.

At more southern (e.g. Muzzle Stream) and northern (e.g. Needles Point) localities, where the thickness of Cretaceous MHF sediments is on the order of 10-20m, the Formation probably represents only the uppermost c.20% of Haumurian time. Although the age of the base of the MHF is probably everywhere Haumurian, time transgressive relationships (younging away from the depocentre) can be inferred. A further corollary is that the base of the *G. circumnodifer* assemblage zone must also be time transgressive and facies dependent.

Because the MHF is overlain in many instances by some form of hiatus, a diachronous pattern for the top of the unit can also be demonstrated (Figures 2.1.2 & A2). Contrasting with the base of the Formation, the upper surface is youngest near the depocentre and becomes progressively older outwards. However, it is possible that the original upper surface of the Formation was nearly isochronous. The youngest ages (Waipawan) for the MHF were recorded at Dart Stream (O30/f140). Early Waipawan ages determined for the lowermost sediments overlying the MHF (i.e. Teredo Limestone) constrain the upper limit of the top of the Formation to lowermost Waipawan (uppermost Paleocene).

Facies Interpretation

The paucity of macrofauna and primary sedimentary structures severely hampers the paleoenvironmental interpretation of the MHF. Information must largely be obtained from microfossil and trace fossil studies, as well as sediment composition.

On both lithologic and paleontological grounds, the base of the MHF corresponds to a major change in marine facies. The underlying non-calcareous siliciclastics of the upper Iwitahi Group are succeeded abruptly by extremely fine grained, biogenic sediments which are essentially free of sandy detritus. A corresponding change in biofacies is represented by an upward change from a purely arenaceous/siliceous fauna (c.20-30 species) into a diverse (100-150 species) assemblage including many calcareous taxa (Webb 1966).

Earlier misidentifications of the MHF as a purely chemical deposit (Thomson 1916, 1919; Prebble 1976) can be attributed to the non-recognition of the biogenic origin of the micritic component.

Intense bioturbation in certain intervals indicates the presence of a vigorous infauna. This high level of biogenic activity, as well as a lack of evidence for either strongly reducing or oxidizing conditions suggests that the upper few metres of sediment were probably aerobic. The lack of a deeply burrowing ichnofauna (e.g. *Zoophycos*), poorly preserved ichnofabric and low diversity of ichnotaxa in the Haumurian sediments, points to important facies differences between uppermost Cretaceous and Lower Paleocene MHF. These features may be attributed to factors such as lower nutritional content, more rapid sedimentation rates, and a less consolidated substrate (Bromley & Ekdale 1986) prior to the K/T boundary.

It is likely that the surficial sediments were in a semi-liquid state because the substrate was apparently not firm enough to support macrobenthics, although this argument fails to account for the absence of pelagic macrofossils. The general lack of large, open burrow systems (e.g. *Thallasinoides*) may be a further indication of the low strength of the sediment, given that it was insufficient to support such structures. Such an interpretation is consistent with a sediment that probably accumulated as a "*soupground*" (Ekdale 1985) from a hemipelagic rain of planktonic debris and clay sized detritus.

Indications of water depths during deposition can be gained from the general preservation of bedding, lack of light-dependent benthic organisms, and paleoecological studies of foraminifera. The preservation of undisturbed, well developed, primary rhythmic bedding lacking any kind of grading indicates accumulation below storm wave base. The absence of coralline algae may suggest a sea bottom below the photic zone. None of the trace fossils are strictly depth diagnostic although in similar chalk facies elsewhere, low diversity, smeared *Planolites*-dominated assemblages (typical of Cretaceous MHF) are considered to be characacteristic of deeper water than *Zoophycos/Teichichnus* (typical of Tertiary MHF) assemblages (Scholle et al. 1983; Ekdale & Bromley 1984).

Foraminifera from thinner sequences south of Branch Stream, indicate water depths equivalent to modern inner to mid shelf conditions (e.g. P31/f14, O31/f181, O30/f56) during the late Haumurian. The relative abundance of pelagic foraminifera suggests that water depths gradually increased northeastwards from outer shelf (P31/f43), to upper slope (P29/f34), into mid to upper bathyal environments (P29/f219).

The relative abundance of chert and low $CaCO_3$ values, may imply that the lowermost MHF near the depocentre was deposited as a dominantly siliceous rather than carbonate ooze. Although it is almost certain that water depths for the MHF did not approach that of the modern lysocline, localized oceanographic conditions may have promoted calcite dissolution in favour of biogenic silica preservation. Subsequent diagenetic effects may have reprecipitated amorphous silica (e.g. radiolaria, diatoms) as chert.

It is difficult, if not impossible, to determine sediment accumulation rates for the MHF because of factors such as post-depositional erosion, the time transgressive nature of the base, and the amount of time not represented across the K/T boundary. However, by comparing the average bed thickness at various locations it can be shown that the rate of accumulation near the depocentre probably exceeded that in shelf environments by a factor of at least two.

The transgressive nature of the base of the MHF suggests a corresponding relative sea level rise. Global sea level curves (Hancock 1975; Vail et al. 1977) indicate a eustatic still stand or even a slight fall during the period of basal MHF transgression. If the published eustatic curves are assumed to be correct, then subsidence must be invoked as a mechanism for transgression. Widespread subsidence, superimposed on what was a very gently sloping shelf, would have caused a rapid landward advance of the shoreline and subsequent starvation of sediment supply.

Judging from the paleoenvironmental data (Appendix I), sea floor gradients were apparently near horizontal, becoming less steep in the Tertiary (0.06°N) than in the Cretaceous (0.20°N). There does not appear to have been any marked break in gradient to indicate a steep slope facies and this is born out by the absence of slump structures. It is more likely that the sediment wedge was deposited as part of a gentle shelf ramp. The term "shelf" is applied here cautiously and not necessarily with the modern depth or morphologic connotations.

Isopachs and depositional trends for the MHF and Woolshed Formation (see Chapter 3.1), suggest a very gentle trough may have existed at the depocentre during early MHF deposition, and it was within this feature that biogenic sedimentation probably initiated. Outward transgression from this depression can be attributed to either regional subsidence or to more localized, active basin sag. If sedimentation kept apace with subsidence, continued downwarping of the basement rocks below the depocentre may have resulted in the observed thickening without further deepening of the trough itself. The presence of the trough may also have been a major factor in the deposition of an initially silica-rich carbonate ooze.

The reasons for the initiation of MHF sedimentation followed by prolonged transgression are not obvious. Firstly, the choking of the of detrital sediment supply may have caused background pelagic sedimentation to become dominant. Secondly, a change in environmental conditions may have stimulated increased plankton production in surficial waters, thereby diluting the clastic input.

The warm temperate conditions which prevailed in New Zealand throughout the Haumurian (Webb 1968; Stevens & Clayton 1971; Strong 1977; Browne 1986) would have favoured the production of micrite via calcareous nannoplankton.

It is likely that a shutdown of clastic sediment input coupled with the existing favourable productivity conditions led to the original transition from siliciclastic to biogenic hemipelagic sedimentation in a protected, shallow trough. As the trough subsided and sediment starvation continued the facies belt widened. A change in the detrital sediment supply is further implied by the difference in the insoluble residue composition between the Woolshed Formation and the MHF. The underlying Woolshed is polymineralic and contains illite and kaolinite, in addition to smectite. The only clay mineral in the MHF is smectite (Appendix II: Figure II.a,b).

The full significance of the Lower Chert Member is, as yet, unclear (see M. Lawrence, in prep.). Chronostratigraphic relationships (Figures A2 & 2.1.2) show that the unit is probably partly coeval with the Claverley Sandstone. This latter facies is interpreted as overlying a non-depositional and submarine erosional surface. It is possible that silica rich sediments (such as the Chert Member) in deeper water represent the offshore manifestations of this hiatus. A variation of surface water conditions (e.g. temperature change or movement of water masses) might lead to increased productivity of siliceous plankton at the expense of calcareous algae, or to dissolution of calcite and a relative enrichment in silica.

The Flaxbourne Limestone Member represents an early transgressive phase of the MHF in the more offshore parts of the basin. Pelagic limestone deposition may have been discontinued by a minor regression and/or by an influx of siliciclastics seaward of the depocentre. The abrupt, *Chondrites*-burrowed, upper contact may be disconformable.

4.2 Teredo Limestone (Formation)

Name And Definition

The Teredo Limestone was defined by Warren & Speden (1978) as the uppermost calcareous Member of the Claverley Sandstone at Haumuri Bluff. The unit was included within the Claverley Sandstone on the basis of what these authors considered to be its close lithologic similarity and conformable contact with that Formation. The derivation of the name stems from the abundance of "*Teredo*" (more properly Clavigellid bivalve) tubes.

Because of its stratigraphic significance, regional extent and lack of lithologic affinity with any other unit, the Teredo Limestone is given separate Formation status. Although its lithologic characteristics vary greatly across the study area, the Teredo Limestone can very broadly be defined as an intensely (*Thallasinoides*) bioturbated, sandy, glauconitic, foraminiferal, micritic limestone.

Neither the presence of Clavigellid tubes, although a common component, nor association with the Claverley Sandstone are intrinsic to the definition of the unit.

Synonomy

The Formation has always been known as Teredo Limestone or upper Teredo Limestone and the original name was introduced by Hector (1874). In several areas, the unit has been misidentified as Claverley Sandstone.

A reference to the "*Kaikoura Greensand*" by Strong (1987), represents usage of an informal field term introduced by this author in conjunction with Strong, during the course of this study, to describe the unit. It is recommended that further usage of this term be discontinued.

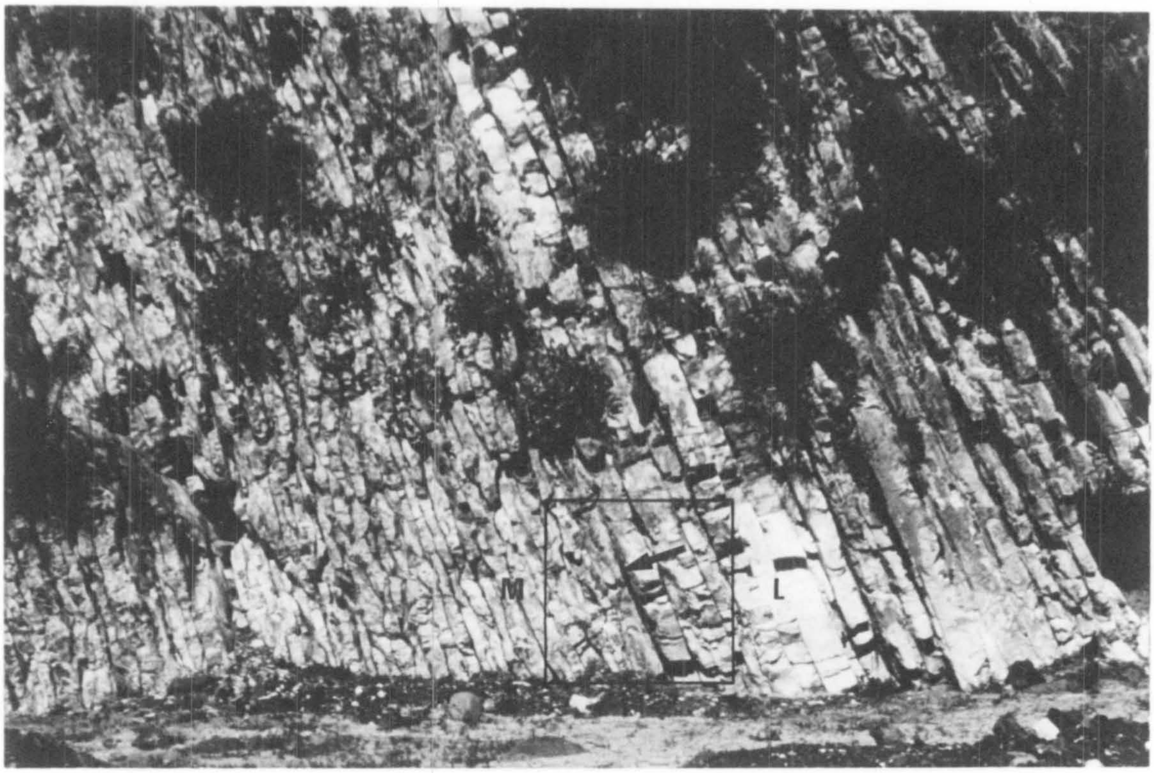
Distribution And Thickness

The Teredo Limestone is present throughout the study area. Between Branch Stream and Woodside Creek, the unit is probably represented by the Upper Chert Member (of the Lower Limestone Formation), which attains a maximum thickness of approximately 3-4m near Mead Stream (see Chapter 4.3).

From Branch Stream, the Teredo Limestone generally thickens south-

Figure 4.2.1: Unconformity (arrowed) between Mead Hill Formation (M) and Teredo Limestone (overlain by Lower Limestone (L)) at Muzzle Stream (S42/923301). Note lack of discordance, but marked difference in appearance of bedding, between Mead Hill Formation and Lower Limestone.

Figure 4.2.2: Detailed view of inset in Figure 4.2.1. Teredo Limestone between arrows.



4.2.1

4.2.2

ward from a minimum of c.10cm (e.g. Dart Stream, Puhi Puhi River) to more than 2m, with a maximum of 4-8m being preserved in the Kaikoura (B) reference section. In several cases, where the Teredo Limestone overlies Claverley Sandstone, but a definite contact could not be found, the unit may be greater than 10m thick.

Northeast of Ben More Stream, the chertified *Thallasinoides* burrows associated with red coloured limestones at Woodside Creek, Needles Point, and Chancet Rocks may penetrate 20m or more into the Mead Hill Formation. The exact thickness of coevally deposited Teredo Limestone, if any existed, is unknown.

Sub-Teredo Limestone Unconformity

Despite outcrop-scale concordance of bedding across its basal contact, all available evidence suggests that the Teredo Limestone overlies a major unconformity. The presence of glauconite, phosphatic nodules, and *Thallasinoides* burrows penetrating into the underlying lithologies points to a significant period of non-deposition prior to accumulation.

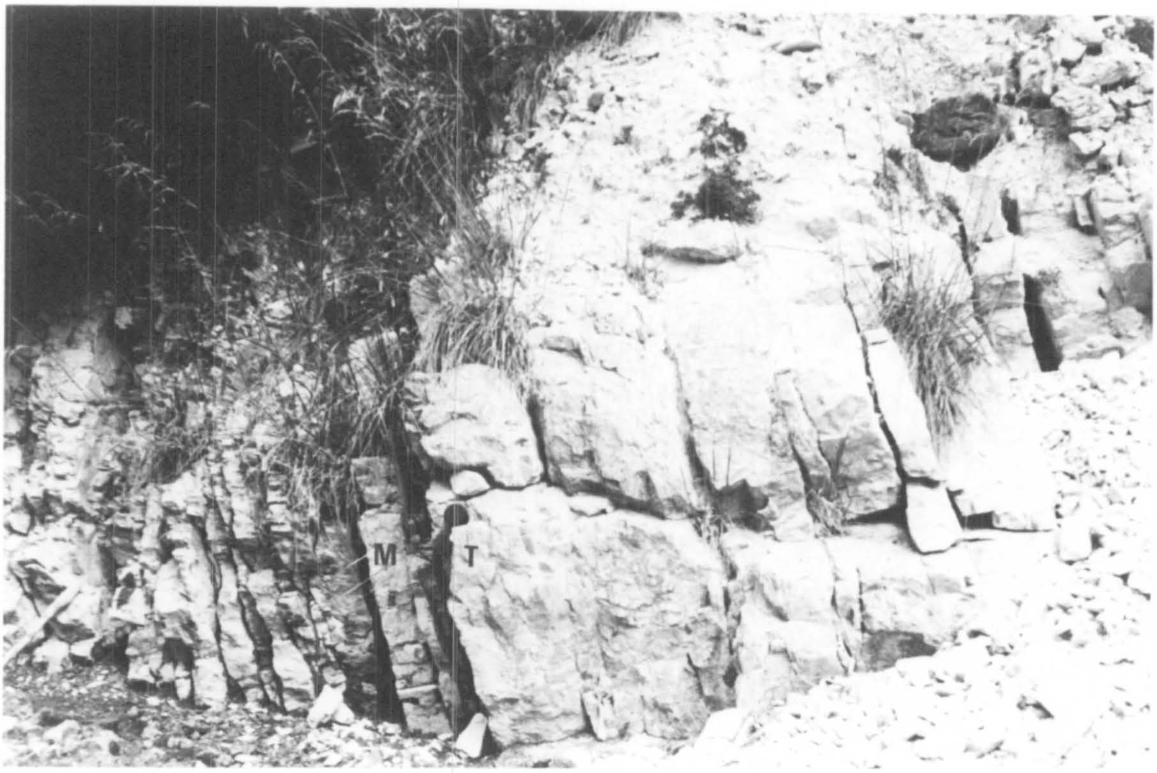
In general, units immediately beneath the Teredo Limestone (and its correlatives) are progressively older and thinner away from Mead Stream, where the stratigraphic break is less pronounced. Variations in this trend indicate localized differential erosion. The lack of discordance across the lower contact in all outcrops contrasts with regional trends which show clear evidence for truncation (Figure 2.1.2). In the south of the study area (e.g. Monkey Face, Kaikoura), the amount of time not represented across the unconformity includes the whole Teurian together with the upper part of the Haumurian and the lower part of the Waipawan Stages (i.e. >10 m.y.).

By comparing sections in which the original thickness of the underlying Mead Hill Formation is unlikely to have been significantly different, the thickness of rock that has been erosional removed can be estimated. Differential erosion between the two Kaikoura reference sections (Figure B1), is at least 30m over a distance of 2km, corresponding to a 0.86° truncation. Regionally, the angle of truncation is likely to have been much lower. Between Bluff Stream and Muzzle Stream (9km), the difference in thickness of the underlying Mead Hill Formation is only 6m indicating a truncational angle of <0.04°.

Chronostratigraphic relations indicate that the maximum angle of

Figure 4.2.3: Teredo Limestone (T) unconformably overlying Mead Hill Formation (M). Bluff Stream (lower) (S42/886253). Lens cap at base of Teredo Limestone for scale.

Figure 4.2.4: Teredo Limestone (T) unconformably overlying Mead Hill Formation (M) at Kaikoura Peninsula (S49/964887). *Thallasinoides* exichnia extend c.10cm into uppermost Mead Hill Formation.



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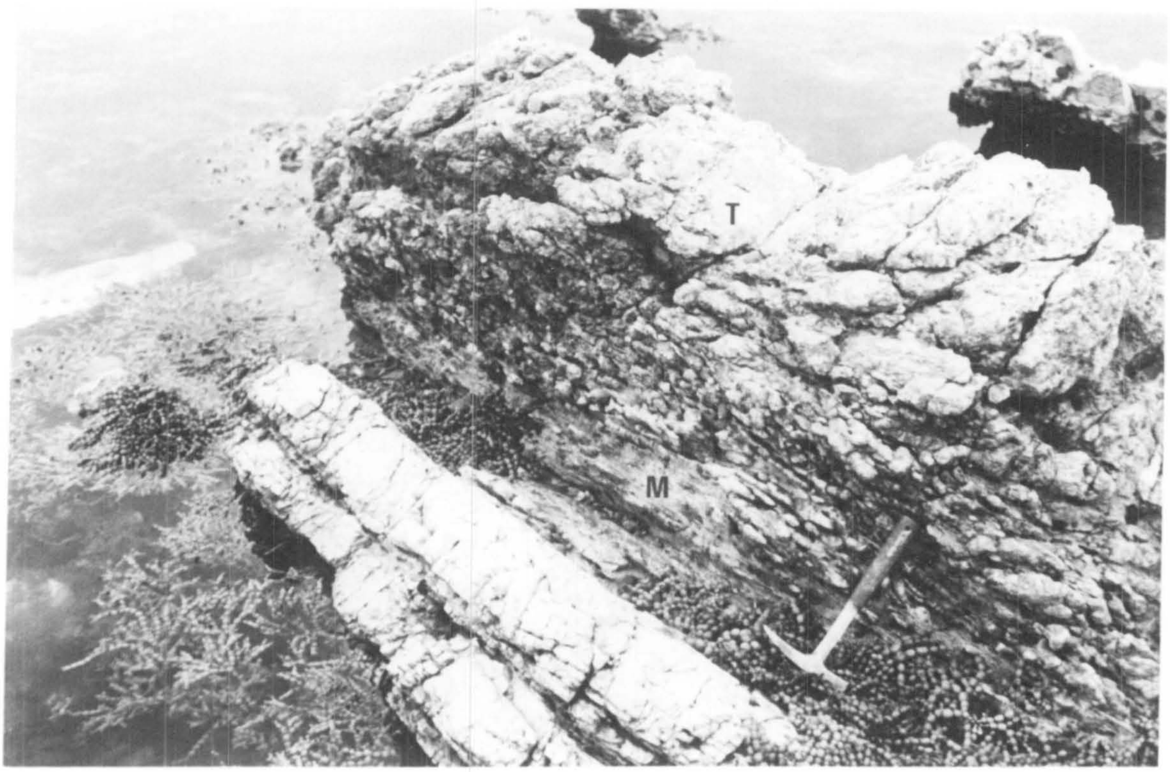


4.2.4

truncation occurs between Dart and Branch Streams (Figure A2). Lithostratigraphic evidence suggests differential erosion of at least 120m of upper Mead Hill Formation over a distance of 3km, translating to at least 2° of angular unconformity.

North of Branch and Wharekiri Streams, there is little or no evidence for erosion beneath the Teredo Limestone. The apparent lack of erosion corresponds to the less abrupt upward lithofacies change between the Mead Hill Formation and the Lower Limestone, and indicates the presence of a less discontinuous sequence. No age difference can be recognized between the top of the Mead Hill Formation and the base of the Lower Limestone in these areas. However, because the very limited age control indicates that both units are partly Waipawan, a break of up to 3m.y. is possible (Figure 1.2).

Type Section

Because of the lateral lithofacies variations and inconsistent stratigraphic relationships, a specific type section can only be nominal. The section through the unit in lower Bluff Stream at S42/886253 (Appendix IV: JM 50A; Figure 4.2.5), is designated as the stratotype because of the unequivocal stratigraphic relationships and presence of a relatively expanded sequence (Figure 4.2.3).

Although the contact is concordant, the unconformity below the Teredo Limestone at that location truncates the Mead Hill Formation. *Thallasinoides* burrows (1cm diameter) extend down from the basal contact up to 50cm into the Mead Hill Formation. Sandstone dikes (1-10cm wide), which penetrate up through the Mead Hill Formation, terminate at the base of the Teredo Limestone. The underlying Mead Hill Formation is upper Haumurian , whereas the overlying Lower Marl is upper Waipawan or lower Mangaorapan (Appendix I).

The Teredo Limestone has a normally graded 20cm basal lag containing sparse, coarse sand to granule size, angular, phosphatized limestone clasts in matrix support. This coarse interval grades up into a poorly bedded, glauconitic (10%), very fine sandy (40%), foraminiferal micrite. Approximately 3m above the basal contact, the unit grades conformably up into the Lower Marl, comprising dcm-bedded marls and calcilutites, containing less than 1% detrital sand and glauconite.

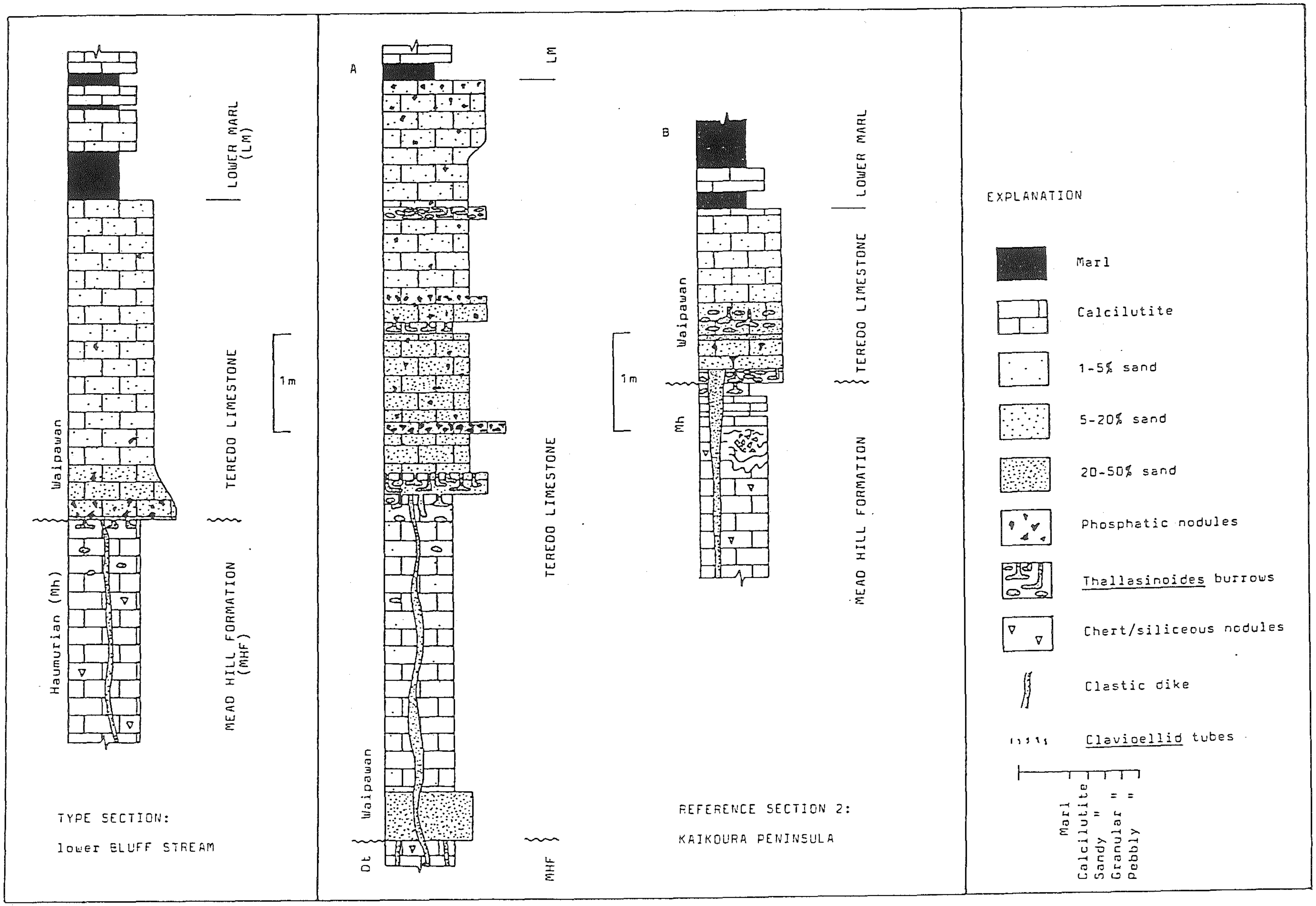


Figure 4.2.5a: Detailed type and reference sections for the Teredo Limestone (see text for locations).

Reference Sections

The following sections are chosen to illustrate the stratigraphic and lithologic variability of the Teredo Limestone throughout the study area.

1. *Muzzle Stream* (S42/923301)

The Teredo Limestone comprises only c.15cm of intensely bioturbated, very glauconitic (23%), sandy (25%) micrite (Figure 4.2.5). Exichnial *Thallasinoides* burrows (1-3cm diameter) extend down 15cm into the Mead Hill Formation; the basal contact is otherwise concordant. A major change in calcilutite lithofacies occurs across the Formation between the underlying Mead Hill Formation and the overlying Lower Limestone. This contrast is especially evident in the style of bedding, which in the Mead Hill Formation is on the order of 8cm and nodular; but planar and 15-20cm thick in the Lower Limestone (Figure 4.2.1-2).

The uppermost Mead Hill Formation is lower Teurian in age while the overlying Lower Limestone is of probable upper Waipawan age (Appendix I).

2. *Kaikoura*

A (South Bay) (S49/983899)

The Teredo Limestone comprises an upper 4m of light grey, glauconitic (10-30%), sandy, foraminiferal micrite containing multiple burrowed and phosphatic horizons, and a lower 50cm of intensely bioturbated micritic greensand (Figure 4.2.5). These two intervals are separated by 3m of relatively sand-free, interbedded calcilutites and marls. *Thallasinoides* burrows extend down from the base of the upper interval to a maximum depth of 1m. The K/T boundary lies 1-2m below the unconformable base of the Teredo Limestone, in the Mead Hill Formation. The thickness of the Mead Hill Formation at this locality is approximately 40m (Appendix IV: JM 1). The Teredo Limestone is conformably overlain by the Lower Marl of Mangaorapan age (Appendix I).

B (Lab Rocks) (S49/964887)

The Teredo Limestone is condensed from >7m in Section A, to a total thickness of less than 1.5m (Figure 4.2.4-5). The lithology in both sections is very similar, although individual horizons cannot be correlated. The lowermost greensand interval at Section A is not present (Appendix IV: JM 4). In addition to the abundance of pebble size, angular, phosphatized calcilutite clasts and intense burrowing by *Thallasi-*

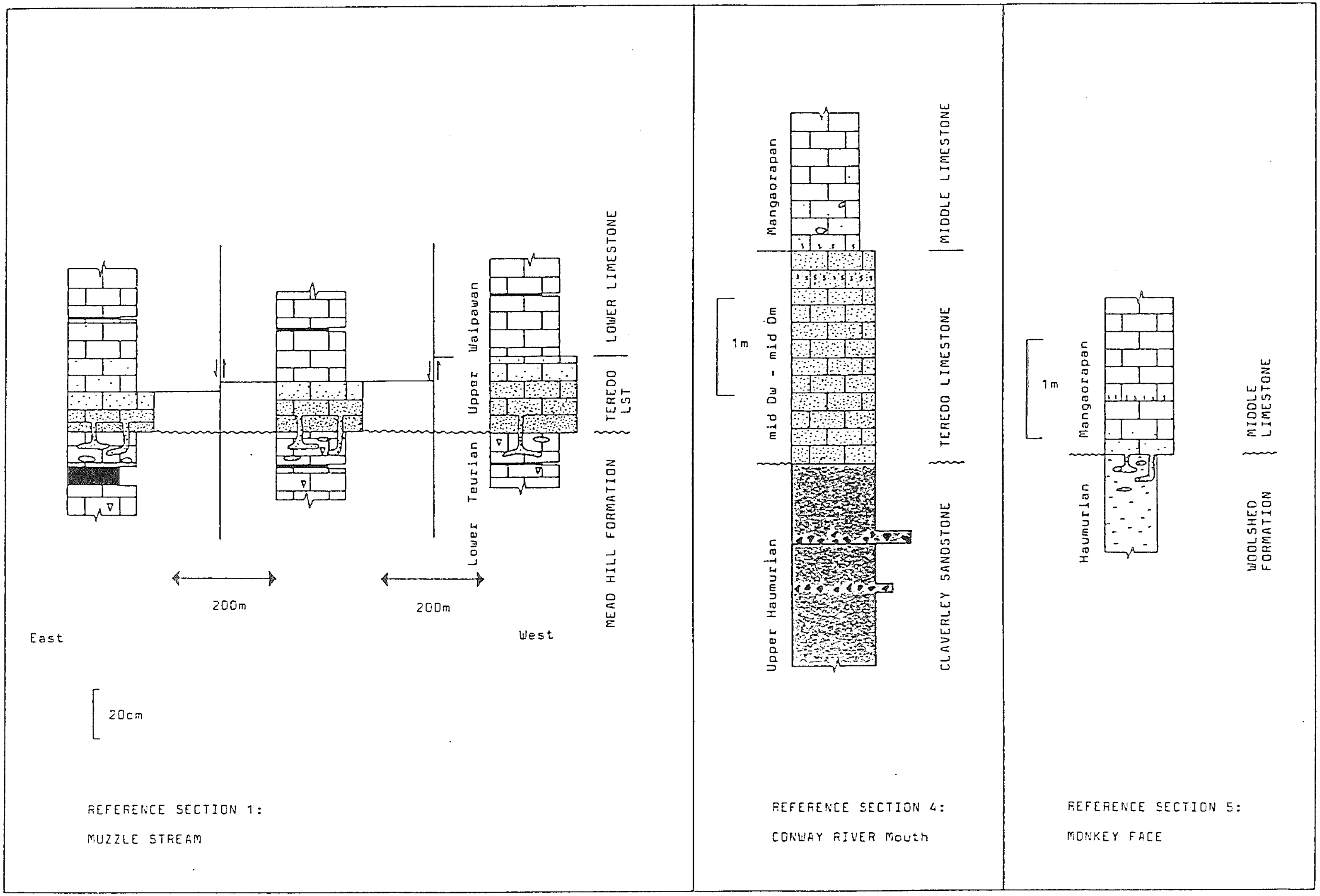
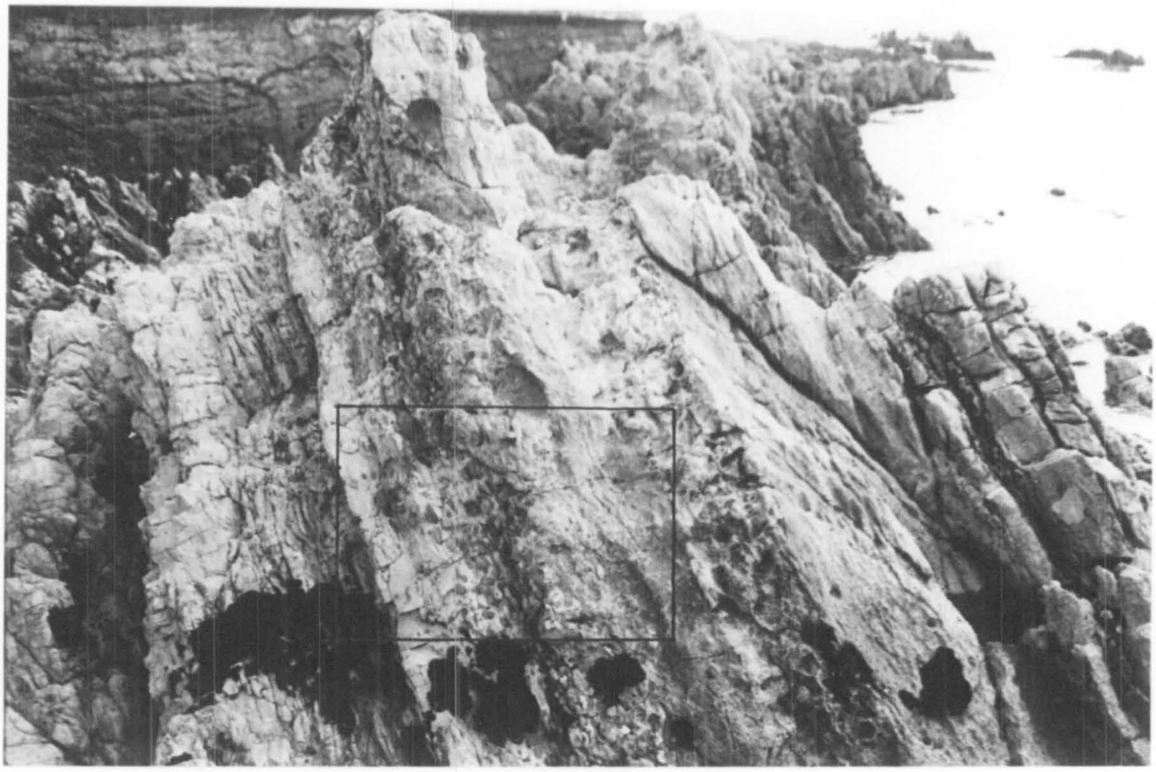


Figure 4.2.5b: Detailed reference sections for the Teredo Limestone (see text for locations, and Figure 4.2.5a for lithologic key).

Figure 4.2.6: Teredo Limestone on the north side of Kaikoura Peninsula (S49/983899).

Figure 4.2.7: Detailed view of inset in Figure 4.2..6. Lens cap for scale.



4.2.6

4.2.7

noides, numerous cetacean(?) bones (<1cm diameter) and shark's teeth are preserved on bedding surfaces. Brecciated pods (<20cm across) extend down 1m into the Mead Hill Formation. These pods contain angular cm-size chips of micritic limestone similar in lithology to the underlying calcilutites of the Mead Hill Formation.

The age of the uppermost Mead Hill Formation is Haumurian, and the Formation is only 10m thick. The Teredo Limestone is also conformably overlain by Lower Marl which is assumed to also be Mangaorapan in age.

In both sections, sandstone dikes can be traced upward through the Mead Hill Formation, into the base of the Teredo Limestone (Figure 4.2.12). These dikes originate from the Claverley Sandstone, or the stratigraphic position normally occupied by that Formation (see Chapter 3).

3. *Puhi Puhi River* (S42/034106).

The Teredo Limestone consists of 1-5cm of very glauconitic, sandy, foraminiferal micrite unconformably overlying c.10m of Mead Hill Formation (Appendix IV: JM 25). *Thallasinoides* burrows extend at least 20cm into nodular-bedded chert and limestone. Burrows penetrate chert nodules and are not significantly deformed by compaction and are not chertified. Bedding within the Mead Hill Formation and the overlying Lower Limestone is concordant. The base of the Lower Limestone, which lacks chert nodules, contains scattered angular granules of phosphatized limestone, chert, and up to 10% sand size glauconite and terrigenous detritals.

4. *Conway River Mouth* (S55/756668).

2.2m of Teredo Limestone overlies Claverley Sandstone and is overlain by Middle Limestone (Figure 4.2.10). The unit is easily distinguishable from the Middle Limestone, but the lower contact with Claverley Sandstone can only be recognized in the field on the basis of $CaCO_3$ content and induration. The Teredo Limestone and Claverley Sandstone contain subequal amounts (c.1%) of glauconite, and their detrital sand fractions have very similar textural and compositional characteristics (see Chapter 6). Both lithologies are equally massive and devoid of macrofossils (Appendix IV: JM 6).

However, petrographic examination reveals that the two lithologies are quite distinct. The underlying Claverley Sandstone is non-calcareous, unfossiliferous and consists of c.90% fine sand in a terrigenous mud matrix, whereas the Teredo Limestone contains >60% micrite, >20% foraminifera, and <15% detrital sand. Phosphatic pebble size clasts which are relatively common in the Claverley Sandstone are absent in the Teredo Limestone. Abundant calcified Clavigellid tubes within the Teredo Limestone are restricted to that unit and to the lowermost 10cm of the overlying Middle Limestone.

The Claverley Sandstone is late Haumurian, whereas the age of the Teredo Limestone itself is constrained as mid Waipawan to mid Mangaorapan. The base of the overlying Middle Limestone is Mangaorapan (Appendix I). These ages suggest that the base of the Teredo Limestone is unconformable. The upper contact with the Middle Limestone, despite its abruptness and marked change in lithofacies, is probably conformable.

5. *Monkey Face* (S49/702894).

The Teredo Limestone is only preserved as infillings within 1-3cm *Thallasinoides* burrows extending 10-20cm into the underlying (Haumurian) Woolshed Formation (Figure 4.2.5). The unconformable contact between the Woolshed Formation and the overlying Middle Limestone (of probable Mangaorapan age) is otherwise concordant. The basal 10cm of calcilutite overlying the Woolshed Formation, contains up to 10% fine sand size glauconite and detritals, which diminish rapidly upwards (Crampton 1985). Numerous Clavigellid tubes occur in the lowermost 2m of Middle Limestone.

6. *Chancet Rocks* (S36/450588).

The base of the Teredo Limestone at Chancet Rocks lies c.12.5m stratigraphically above the K/T boundary in a near vertically dipping sequence. The unit is represented by horizontal silicified burrows within a lower 15m sequence of pink, red and maroon coloured micritic limestones, and by abundant vertically cylindrical chert nodules (Figure 4.2.13) in the overlying 15m+ of similar, but light grey, limestones. It is the chertified burrows, and not the enclosing micrites, which constitute the Formation.

The exact stratigraphic relationships are not certain, primarily because of the paucity of micropaleontological data. However, the limited volume of evidence suggests that the burrows are of Waipawan age. The nature of the upper contact is unknown due to the poor exposure.

Burrows within the lower interval of reddish coloured limestones are identified as networks of 1-2cm diameter *Thallasinoides*. The silicification process has resulted in the formation of chert in the core of most burrows. Glauconitic, sandy debris is rarely present in the less silicified tubes.

The cylindrical nodules in the overlying sequence have previously been described in detail (McCulloch 1976; Lewis & Laird 1980). Most chert nodules consist of a central 1-4cm diameter vertical rod surrounded by a 15-20cm concentric hollow cylinder with 1-4cm thick walls (Figure 4.2.13). Siliceous calcilutite, similar to the enclosing sediment, is preserved between this outer ring and the central rod. Nodules extend up to 50cm perpendicular to bedding, and commonly display a bulbous termination at their base. In several cases, where the central canal is less silicified, glauconite and detrital sand are present.

Lithology

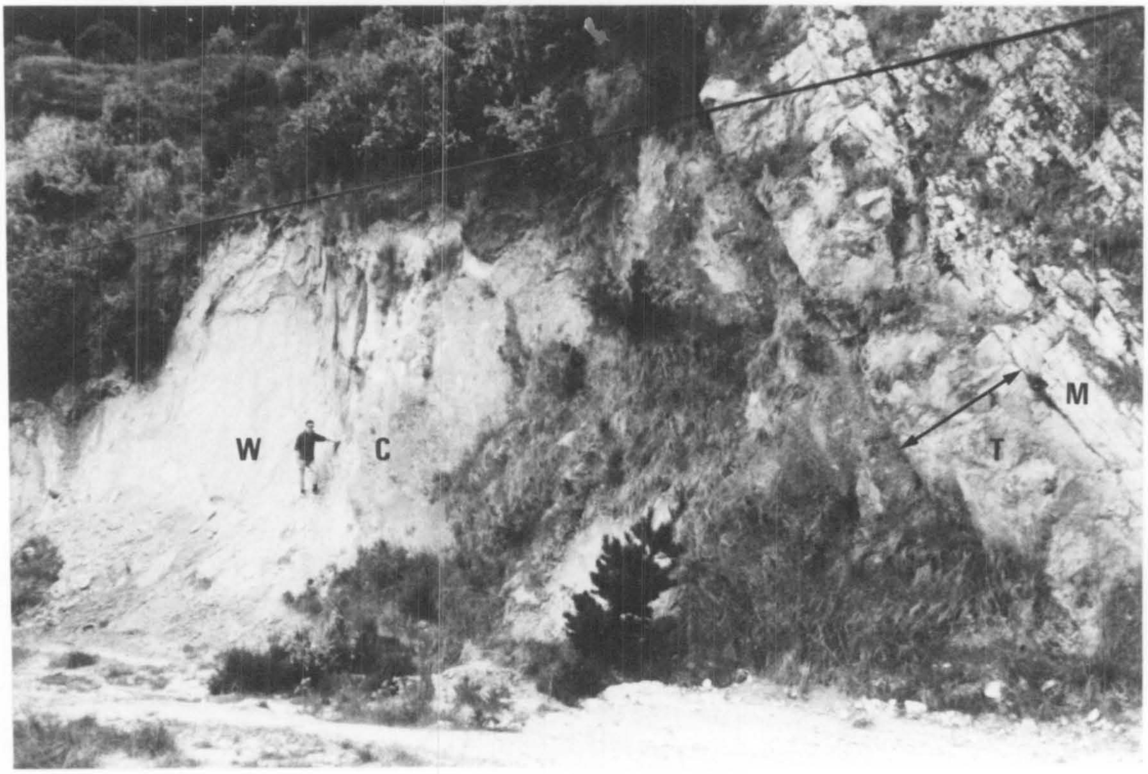
The petrography of the sandy facies of the Teredo Limestone is discussed in Chapter 6.1. Although the Formation can resemble a glauconitic sandstone in the field, the dominant (>50%) component is always micrite. Sand-sized glauconite, terrigenous detritals and foraminifera dilute the lithology to various extents. The presence of abundant, well preserved planktonic foraminifera allows discrimination between the Teredo Limestone and the superficially similar Claverley Sandstone.

The ability to distinguish the two units is necessary, because they can occupy similar stratigraphic positions, and can be difficult to differentiate from field characteristics alone. In Figure 3.2.8, the Claverley Sandstone is conformably overlain by interbedded calcilutites and marls of the Mead Hill Formation (Haumurian in age), whereas the sequence displayed in Figure 4.2.11 shows the Teredo Limestone in a similar relationship with the Middle Limestone (Mangaorapan). Only when viewed petrographically and in regional overview, does it become obvious that the two sequences are not correlative.

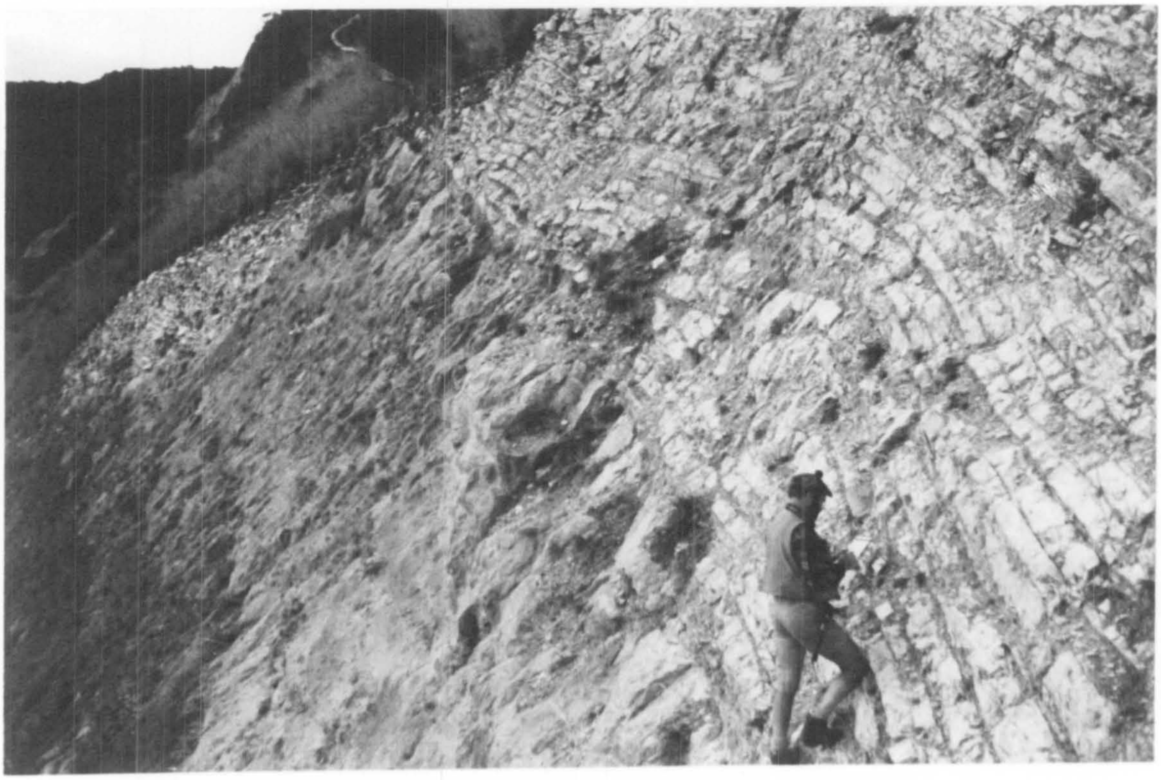
South of Branch Stream, non-micritic components comprise up to 50% of the lithology, and phosphatic clasts are ubiquitous. The Teredo Limestone passes laterally northward into the coeval Upper Chert Member (of the Lower Limestone Formation). Phosphatic clasts and glauconite are conspicuously absent, as are the *Thallasinoides* burrows which are ubiquitous in northern and southern facies equivalents. Although moder-

Figure 4.2.10: Woolshed Formation (W) unconformably overlain by Claverley Sandstone (C). Hand resting on contact. Limits of Teredo Limestone (T) indicated by arrows. Teredo Limestone conformably overlain by Middle Limestone (M). Conway River mouth (S55/756668).

Figure 4.2.11: Well bedded facies of Middle Limestone conformably overlying Teredo Limestone. Feet resting on contact. Haumuri Bluff (S56/797724).



4.2.10



4.2.11

ately bioturbated by a *Zoophycos-Planolites* assemblage, dark sediment-infilled burrows do not penetrate into the underlying lighter coloured micritic limestones.

The Upper Chert Member passes laterally northward into silicified burrows in, and overlying, the pink and red limestone interval which extends from Woodside Creek in the south to Chancet Rocks in the north. Geochemical analysis and petrographic examination failed to detect any anomalously high ferrugenous component or associated volcanic detritus to explain the red colouration. The presence of excess goethite or hematite is suggested by the natural remanant magnetizations which are approximately 1 order of magnitude greater than those of the underlying light grey limestones (J.A. Tarduno pers. comm. 1986).

Apart from intense bioturbation and distinctive colouration, the composition of this interval is indistinguishable from that of the enclosing Mead Hill Formation. Although intercalated marls and non-biogenic sedimentary structures are absent, bedding is defined by zones of burrowing and colour contrast. The intensity of bioturbation increases in proportion to the degree of red colouration. Coarser concentrations of terrigenous sand, glauconite and foraminifera are not found outside *Thallasinoides* burrows. No evidence of phophatization was discovered in this northern facies.

Paleontology

The only macrofossils present within the Teredo Limestone are very rare, poorly preserved, phosphatized vertebrate (i.e. shark and cetacean) teeth and bones. Although indeterminate echinodermal and molluscan fragments are commonly present in minor quantities, no intact specimen was discovered.

The microfossil component is dominated by generally well preserved planktonic foraminifera. Calcareous benthics are outweighed numerically by plantics in a ratio of 10:1. Sponge spicules are occasionally present in significant quantities (<4%), although petrographic evidence suggests that most, if not all, are reworked from the underlying Claverley Sandstone (see Chapter 6.2).

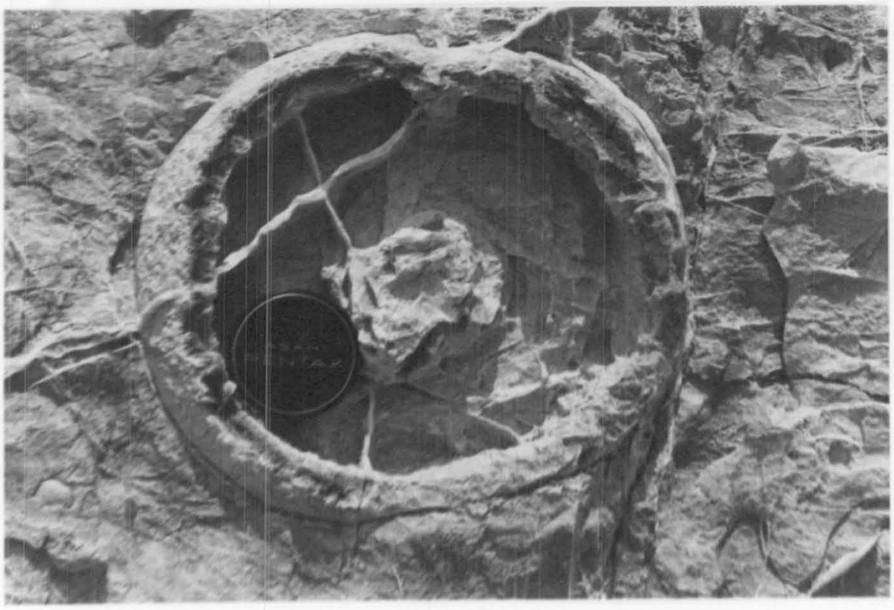
Ichnology

The presence of a vigorous infauna is suggested by the high degree of bioturbation. *Thallasinoides* burrows are common to both southern and

Figure 4.2.12: Clastic dike (arrowed) feeding Teredo Limestone. Kaikoura Peninsula (S49/983899).

Figure 4.2.13: Plan view if vertical *Thallasinoides* shaft (T), surrounded by cylindrical halo of chert. Chancet Rocks (S36/450588).

4.2.12



4.2.13

northern facies but are apparently absent from the Upper Chert Member in central Marlborough. South of Branch Stream, where sub-Teredo Limestone erosion has been most extensive, *Thallasinoides* burrows penetrate up to 1m into the underlying limestone (Mead Hill Formation) or siltstone (Woolshed Formation). In these cases, the basal sediments of the Teredo Limestone have passively infilled the burrows. The sharply defined, unsupported and undeformed nature of the burrow walls may indicate that in each case the host sediment was partly lithified during burrowing. Where the Teredo Limestone overlies Claverley Sandstone, no evidence of *Thallasinoides* burrowing could be detected, indicating a possible substrate dependence of that ichnofauna.

The cylindrical chert nodules overlying the reddish limestones in the northern facies have long been accepted as fossil sponges (McCulloch 1976; Lensen 1978b; Lewis & Laird 1980). Subsequent reinterpretations (A. Seilacher in Lewis 1984) suggest that many, but not all, may be "paramoudra" trace fossils similar to those found in the European Chalk. Whereas many forms superficially resemble *Bathichnus paramoudrae*, the most recent expert opinion (A.A. Ekdale pers. comm. 1986) suggests that this is not the case. Descriptions of *B. paramoudrae* (Bromley et al. 1975; Bromley & Ekdale 1984b) include a very thin canal of glauconite within the central rod. Such a structure has not yet been recorded from any nodule at Chancet Rocks.

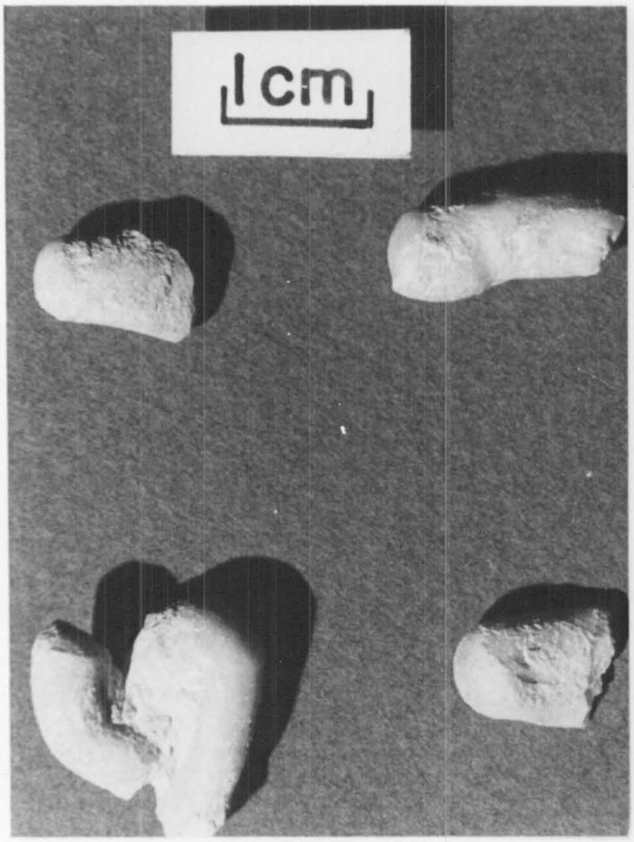
The absence of a concentration a sponge spicules in either the nodules themselves or in the surrounding sediment, together with the lack of expert zoological identification, argues against a sponge origin.

Detrital sand and glauconite within the central rods of several structures, together with the abundance of horizontal networks of chertified *Thallasinoides* burrows of similar morphology several metres below, argue for an ichnologic origin. It is more likely that the central tube represents the vertical "escape" shaft of *Thallasinoides*.

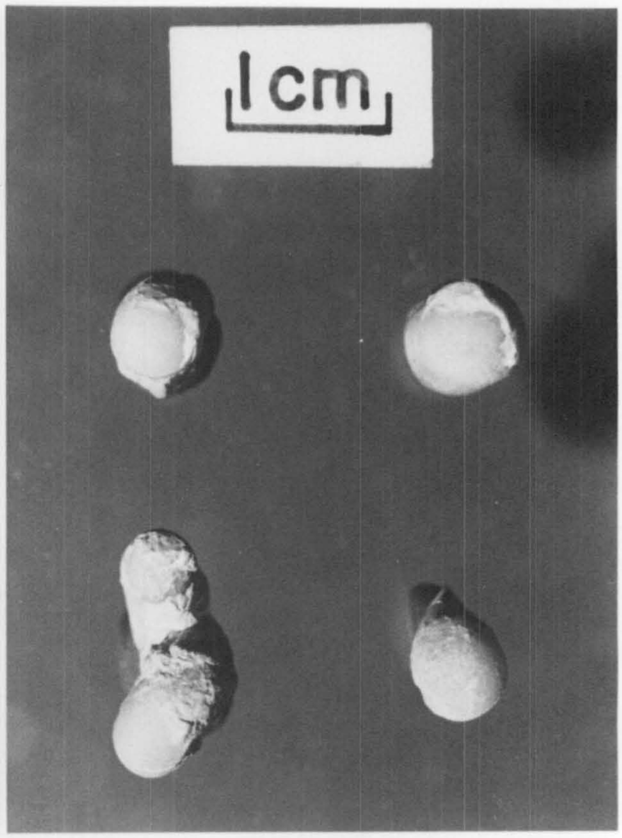
Decomposition of organic remains may have produced a chemical environment favouring chertification of the burrow system (e.g. Ekdale & Harlick 1986). Silicification of the surrounding cylindrical halo would have been produced by the external chemical gradient. A similar mechanism has been proposed to explain the morphology and genesis of *B. paramoudrae* (Bromley et al. 1975). The same environment would also help to

Figure 4.2.15a,b: Section (a) and plan (b) view of Clavigellid bivalve tubes and body fossils.

Figure 4.2.16a,b: Plan view of in situ specimens of Clavigellids.



4.2.15a



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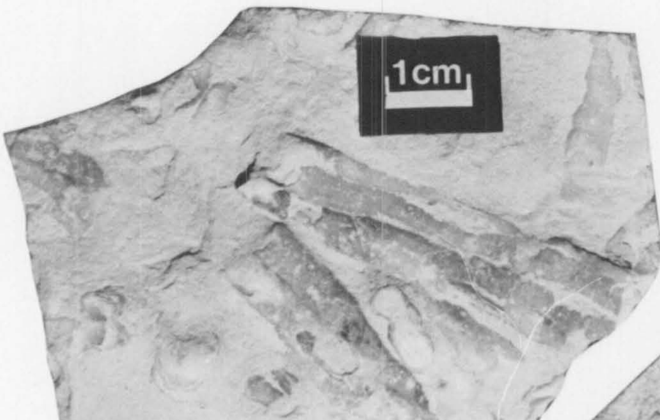


4.2.16a

4.2.16b

explain the red colouration in the underlying horizontal burrow systems. Circulation of oxygenated water to these lower networks would convert elemental iron to hematite rather than pyrite, which is the common product of organic decomposition.

Clusters of horizontal, 5mm diameter, sediment-infilled, calcitic tubes, which are abundant throughout the unit, were originally thought to be *Teredo* remains (Hector 1874). They have subsequently have been identified by Warren & Speden (1978) as Clavigellid bivalve tubes. These differ from teredinids in that they are able to bore or burrow into both hard and soft substrates, whereas teredinids bore exclusively in wood.

Each of the four specimens in Figure 4.2.15 displays the intact valve of *Clavigella* at the termination of the tube. In many cases a central longitudinal groove is present which may record the passage of the valve hinge (Figure 4.2.16). Because one or both valves are secreted to the tube (Seilacher 1984), it is problematical as to whether the structure should be considered as a body or trace fossil.

Although many modern Clavigellid species are confined to very shallow water, they are known from deeper environments. Clavigellids inhabiting hardgrounds (therefore not needing a protective tube), which may have developed on the sub-Teredo Limestone unconformity, may have been forced to make morphological adjustments as less stable sediments accumulated.

The Clavigellid tubes occupy a relatively isochronous horizon in southern and central parts of the study area. Tubes in the Lower Limestone may represent (pelagic?) juveniles transported northward from the coeval sandy facies of the Teredo Limestone.

Age

The age of the Teredo Limestone ranges from Waipawan to Mangaorapan and possibly Heretaungan (Appendix I). Although direct micropaleontological determinations have been made, in many cases the age of the Teredo Limestone has been inferred from the age of the lowermost overlying sediments. Because the contact with the underlying formations is always unconformable, their age provides a maximum age constraint.

Chronostratigraphic relationships (see Figure 2.1.2) show that the

Formation becomes younger southward from Branch Stream, where the Teredo Limestone is Waipawan. At Conway River, marking the southern limit of the study area, the unit is dated as mid Waipawan to mid Mangaorapan. At Seymour Stream, the base of the overlying Lower Marl is Heretaungan, suggesting a late Mangaorapan or even Heretaungan age for the Teredo Limestone. Waipawan or younger dinoflagellates were recovered from a phosphatized pebble in the Teredo Limestone at Haumuri Bluff (Wilson 1983). This age does not necessarily date the Teredo Limestone because the clast may be reworked from the underlying Mead Hill Formation which has been eroded away.

The age of the Formation is less well constrained to the north of Branch Stream, and there is only very scant data from Woodside Creek north. At Mead Stream, the Upper Chert Member is Waipawan (O30/f97-99). Available evidence indicates that the correlative of the Teredo Limestone between Woodside Creek and Chancet Rocks, is of Waipawan age (S36/f783). The Teurian date cited by McCulloch (1976) almost certainly reflects sampling from the sediment surrounding the burrows, which is actually part of the Mead Hill Formation. The age of the burrows, which may have penetrated very deeply into the Mead Hill Formation, bears no relationship to the surrounding sediments other than being younger.

Facies Interpretation

The paleobathymetry indicated by the overwhelming predominance of planktonic microfauna within the Teredo Limestone and the immediately overlying sediments, suggests deep marine conditions prevailed. Paleoenvironmental interpretations of the foraminiferal component indicate that the setting was oceanic and probably bathyal (Appendix I).

The Teredo Limestone can be divided into three geographically separate facies. South of Branch Stream, a southern facies can be differentiated on the basis of its large sandy component (see Chapter 6.2). The central facies, between Branch Stream and Woodside Creek, is represented by the Upper Chert Member of the Lower Limestone Formation (see Chapter 4.3). Although a marked change in lithology occurs at the base of the Member, there is little evidence to suggest that significant erosion occurred prior to its deposition. The laminated, very fine grained lithology, abundance of pyrite and absence of *Thallasinoides* suggests deposition in a low energy environment. An approximation of paleobathymetry can be gained from the foraminiferal content of the enclosing sediments which suggest bathyal marine conditions.

Between Woodside Creek and Chancet Rocks, the northern facies is distinguishable only by the concentration of *Thallasinoides* and the red discolouration of the enclosing Mead Hill Formation. This northern facies is preserved only as the network of silicified burrows and does not include the surrounding sediments. The actual bedding surface(s) from which these burrows originate is not exposed.

On the basis of the association of silicified *Thallasinoides* burrows with periods of non-deposition in similar lithologies elsewhere (e.g. Kennedy & Garrison 1975; Ekdale & Bromley 1984b), a similar interpretation can be extended to this facies. A long period of non-deposition is further inferred by the great depth of burrowing. Lewis & Laird (1980) suggest a mid shelf to mid slope paleoenvironmental setting, although this interpretation probably reflects sampling in the surrounding, probably much older, Mead Hill Formation, rather than in the burrows themselves.

The initial interpretation by McCulloch (1976), and subsequently by Lewis & Laird (1980), involving deposition of the surrounding micritic sediments from sediment gravity flows cannot be substantiated. Their hypotheses depends entirely on a sponge origin for the cylindrical chert nodules which are clearly burrows. The lack of sedimentary structures within the enclosing sediments, supportive of a calci-turbiditic origin (e.g. grading of foraminifera) also fails to support their argument.

The association of the interval with volcanic activity proposed by McCulloch (1976), is based entirely on the assumption that the red colouration results from the presence of volcanically-derived iron. Despite extensive searching the "*rare boulders of tuff in pink limestone*" (Lensen 1962) were not found during this study. Because the anomalous colour may well be a later biochemical effect, and contemporaneous volcanic activity of Waipawan age is unknown in New Zealand, the suggested volcanic association is unlikely.

Evidence has yet to be found for subaerial exposure (e.g. karsting, etc.) on the underlying erosional surface. It can therefore be assumed that the erosional processes preceding deposition of the Teredo Limestone in the study area were wholly submarine. The ubiquity of *Thallasinoides* burrows and phosphatic clasts is indicative of a lengthy period of non-deposition following erosion. The textural characteristics of the Teredo Limestone (see Chapter 6.2), indicate accumulation under the influence of waning currents.

Possibly during, and certainly following, active erosion it is likely that at least one hardground formed in order to produce angular phosphatized clasts. Similar horizons throughout Europe, are commonly interpreted to result from periods of non-deposition in fine grained carbonates (Bromley 1967; Kennedy & Garrison 1975). The presence of multiple *Thallasinoides*/nodular phosphate horizons indicates possible fluctuations in the intensity of bottom currents. At Kaikoura, where the Teredo Limestone is relatively expanded, either rates of sedimentation were abnormally high or the final erosive event was less pronounced, and was unable to remove the early formed hardgrounds.

The nature of the Teredo Limestone and its relation to underlying rocks, indicates that a significant depositional break, which was most pronounced in southern Marlborough, occurred throughout the study area during the Early Eocene. The regional discordance associated with this hiatus (Figure 2.1.2), at least below the southern facies, cannot be explained entirely in terms of submarine current action. Widespread, low-angle tilting of the sea floor caused southern areas to be uplifted allowing deeper erosion. Contemporaneous tectonic activity is evidenced by sandstone dike emplacement and probable extrusion onto the sea floor. The Claverley Sandstone may have become overpressured during burial compaction. Additional (compressional?) tectonic activity led to cap rock (Mead Hill Formation) fracturing and upward sediment expulsion.

Based on the degree of differential erosion, which probably reflects differential uplift, the intensity of tectonic activity is unlikely to have been intense. A minor latest Paleocene reactivation of basement structures has been recognized in the Taranaki Basin (Knox 1982). Apart from this event, there is virtually no record of tectonism or volcanism during the Waipawan and Mangaorapan Stages in New Zealand (see Lillie 1980, p356), which further supports the mild and probably local nature of that found in Marlborough. The timing of this tectonic pulse approximately coincides with the cessation of sea-floor spreading in the Tasman Sea (see Chapter 1). The resultant change in stress may have caused local reactivation of basement faults, uplift, and consequent unconformity development.

Correlative unconformities of a similar age, have not been reported from the onland New Zealand stratigraphic record. DSDP cores recovered during Leg XXI show a strong angular unconformity separating Late Paleocene from Early Eocene sediments in the Tasman Sea (Edwards 1973b). The oldest sediments overlying this hiatus are of mid Waipawan age. A marked disconformity near base Eocene has been reported from the Taranaki Basin (Knox 1982). Based on available data, any link between these hiatuses and the sub-Teredo Limestone unconformity in Marlborough can only be speculative. Wider correlation and reinvestigation of onland sequences, will be necessary to ascertain the significance of the event.

It is unlikely that the coincidence of increased submarine current activity with a minor tectonic pulse is accidental. The associated tectonic event may have been wholly intrabasinal and related to reactivation of basement faults, which are inferred to have played a significant role in the depositional patterns in Marlborough during the latter part of the Cretaceous (M. Laird, NZGS, pers. comm. 1987). Resulting localized submarine topographic changes may have opened channels linking existing major oceanic deep sea currents to Marlborough.

4.3 Lower Limestone (Formation)

Name And Definition

The name Lower Limestone was first introduced by Hall (1964) to describe "*hard, white argillaceous limestone with rare siltstone partings ... conformably overlain by Lower Bentonite*" near Swale Stream. Prebble's (1976) subsequent definition did not significantly change the earlier description.

The Lower Limestone consists of 10-20cm thick, light greenish grey, very well indurated, muddy, foraminiferal micritic limestones interbedded with 1-10mm thick, light to medium grey, poorly indurated, micritic, smectite mudstones or marls.

Because of its substantial thickness (c.70m), regional extent, practicability for mapping and continuity throughout Marlborough, the Lower Limestone is best considered as a Formation within the Amuri Limestone Group. The Upper Chert Member is contained within the Lower Limestone.

Synonomy

The Formation has always been known as Lower Limestone, but has previously been considered a Member of the Amuri Limestone (see Figure 2.2.1).

Distribution And Thickness

The outcrop pattern of the Lower Limestone is very similar to that of the Mead Hill Formation, although the unit does not extend as far south as Kaikoura or Limestone Hill (Figure 4.3.1). The unit wedges out to the SW between Bluff and Gentle Annie Streams in inland areas, and approximately 5km north of Kaikoura in near-coastal sections. The Formation is not known to the north of the Ure (Waima) River.

A maximum thickness of c.78m is achieved near Mead Stream. Isopach variations indicate that, although the Formation was deposited within a basin of similar proportions to that during accumulation of the Mead Hill Formation, the depocentre or central trough had migrated some 5km SW. The overall basin configuration, inferred from isopachs, is that of a symmetrical NW-trending trough which shallowed to the SE.

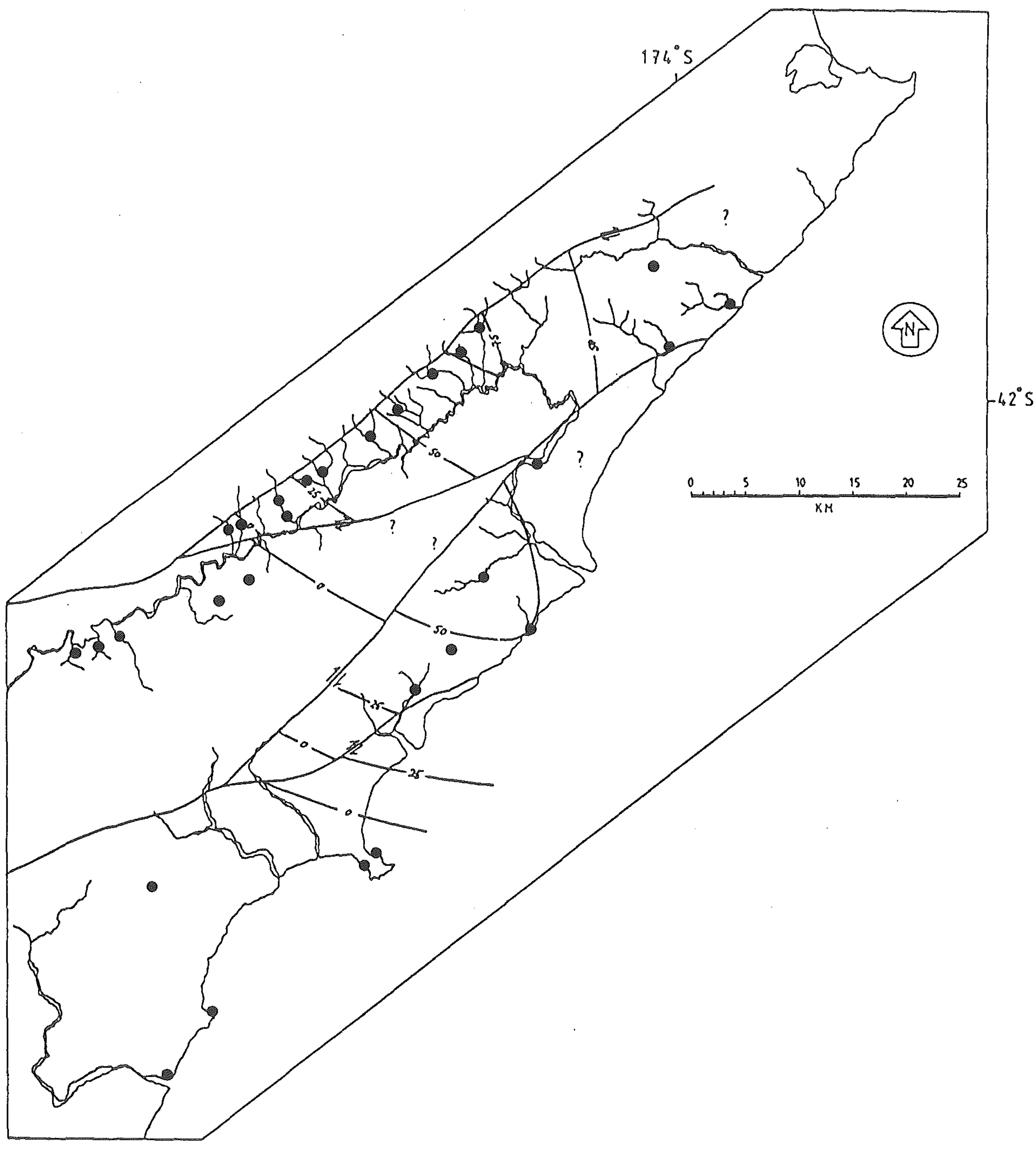


Figure 4.3.1: Paleoisopach map for the Lower Limestone. Contours in metres. Location of measured sections shown in Figure 4.1.1.

Relation To Underlying Rocks

Near the basin depocentre, the Upper Chert Member (at the base of the Lower Limestone) abruptly overlies the Mead Hill Formation. South of Dart Stream, the Formation conformably overlies Teredo Limestone. The contact is generally sharp although small quantities of sandy detritus persist from the Teredo Limestone upwards into the basal 10-100cm of the Lower Limestone.

Type Section

Neither Hall (1964) nor Prebble (1976) provided either a stratotype or reference section for the Lower Limestone. The best exposed, most readily accessible and continuous section occurs in Mead Stream between S35/082448 and S35/078448 (Appendix IV: JM 30). For these reasons, and because of the exposure of conformable contacts with the underlying Mead Hill Formation and overlying Lower Marl at this locality, the Mead Stream section is designated the type section.

The Formation is 78m thick and consists of 10cm-thick, light greenish grey, well indurated, foraminiferal micritic limestones and interbedded 1-5mm marls. Chert is present above the Upper Chert Member as small isolated nodules comprising less than 5% of the rock. 45m above the base of the Formation, the volume of chert increases abruptly to 30-35% throughout an 8m interval. In this zone, chert forms 5-10cm thick, continuous bands near the centre of limestone beds (Fig 4.3.4).

a) *Upper Chert Member* (030/082448)

The type section for the Upper Chert Member in Mead Stream coincides with the lowermost 2.7m of the stratotype for the Lower Limestone Formation. The Member consists of interbedded (5-10cm scale), rusty weathering, slightly silty chert and greenish black, non-calcareous, pyritic mudstones (Figure 4.3.5). The Upper Chert Member rests sharply on interbedded 20-30cm thick, light grey, well indurated, moderately (30%) cherty, micritic limestones and thin marls of the Mead Hill Formation. The top of the Member is marked by a sharp transition into the light grey, micritic limestones which comprise the remainder of the Lower Limestone.

Lithology

There is almost no variation in the lithology of the Lower Limestone throughout the study area. Average calcilutite bed thickness decreases only slightly south of the depocentre. Intercalated marls

Figure 4.3.2: Intensely *Zoophycos* bioturbated sequence of Lower Limestone. Mead Stream (S35/079448).

Figure 4.3.3: Detailed view of 2 small *Zoophycos* structures in Lower Limestone. Mead Stream (S35/079448).

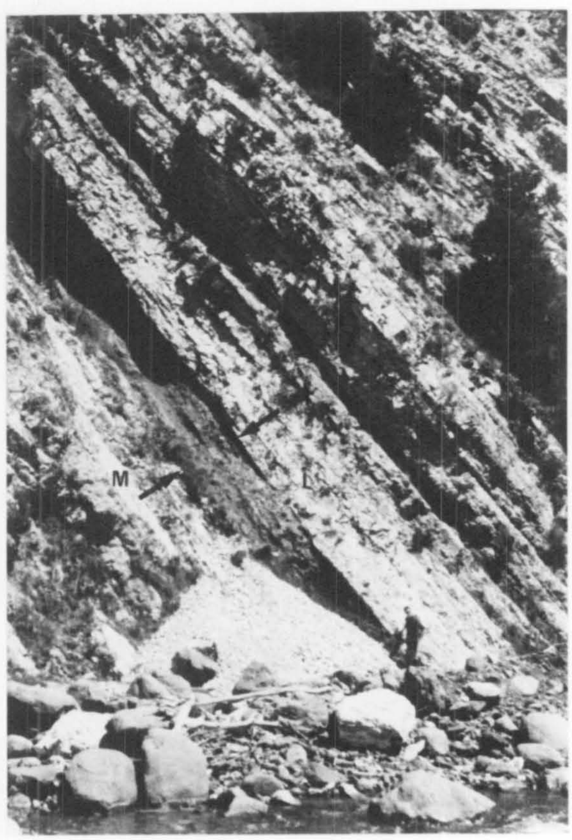
Figure 4.3.4: Coalescing chert nodules in the Lower Limestone. Mead Stream (S35/081448).

Figure 4.3.5: Upper Chert Member (between arrows) of Lower Limestone. Mead Stream (S35/082448). M=Mead Hill Formation. L=Lower Limestone.

4.3.2

4.3.3

4.3.4



4.3.5

near the top of the unit generally become thicker as the Formation thickness decreases southward. Anomalous 10cm thick marls occur sporadically throughout the sequence.

No evidence of sedimentary structures (apart from bedding), intercalated siliciclastics, or calcarenites was discovered. Bedding surfaces are very planar and nodular distortion, which is typical in the Mead Hill Formation is uncommon. The basal 3m of limestone overlying the Upper Chert Member, is stylolitized and original bedding planes are difficult to recognize in this interval. Stylolites are not developed elsewhere in the Formation. Dolomite is conspicuously absent from the Lower Limestone.

Chert is only found in quantities exceeding 5% in the vicinity of the depocentre and there, only rarely exceeds 10%. The Upper Chert Member can be traced, with little variation in either thickness or composition, from Mead Stream south as far as Dee Stream (6.5km). At Branch Stream (10km south of Mead Stream), the Member is present as a 3m interval of limestone containing 10% chert nodules. The anomalous 8m interval of banded chert described at Mead Stream probably correlates with an interval of increased (c.10%) chert volume, occupying a similar stratigraphic position at Dee Stream (Appendix IV: JM 32). Neither the Upper Chert Member nor the banded chert interval can be traced north of Mead Stream.

Calcilutites are texturally mudstones and compositionally micrites or fossiliferous micrites. Well preserved foraminifera rarely exceed more than 5%, and commonly comprise 1-2% of the sediment. Rare, poorly preserved radiolaria comprise the remainder (<<1%) of the microfossil component. Macrofossil debris is rare.

Silt or coarser size detritus is extremely rare and usually found only near the base of the Lower Limestone either in the Upper Chert Member or where the Formation overlies the Teredo Limestone.

Geochemical analysis (Appendix II) shows that Lower Limestone calcilutites are composed of $CaCO_3$ (c.78%), quartz (c.13%), and smectite (c.8%); illite was not detected. Quantitative XRF results indicate the presence of minor quantities of barite (<0.5%); this was undetected in XRD traces.

Insoluble residue analysis indicates the presence of 81% SiO_2 in the non-carbonate fraction, which corresponds to a value of 60-66% quartz. Cristobalite was not detected in any sample. Because the amount of silt-size quartz is relatively low, these high values may indicate a high degree of diagenetic silicification in the Lower Limestone.

Marls have a similar petrographic texture and composition to that of the associated calcilutites. Significant differences occur in their clay mineral fraction which approaches 13% in whole rocks (c.f. calcilutites c.8%). The overall composition of marls is $CaCO_3$ (c.78%), quartz (c.9%), smectite (c.9%), illite (c.4%), together with minor amounts of barite. Despite their lesser induration, marls have $CaCO_3$ values which are approximately the same as limestones. Marls have an insoluble residue SiO_2 total of c.60%, which approximates to a non-carbonate modal quartz value of 43%.

Paleontology

No macrofossils were observed in the Lower Limestone. Prebble (1976) described what he thought to be silicified sponge remains from the Formation in Isolation Creek. These "sponges" are interpreted (see Chapter 4.2) as silicified burrows extending into the upper part of the Mead Hill Formation. The foraminiferal component is >95% planktonic.

Ichnology

Bioturbation structures are extremely well preserved in the Lower Limestone calcilutites. The ichnoassemblage includes *Planolites* and *Teichichnus*, but is dominated by abundant *Zoophycos*. As many as 21 closely spaced (1cm) spreiten levels are stacked in some of the smaller diameter (c.15cm) structures (Figure 4.3.3). Where individual burrow systems extend over a larger diameter (>2m), the number of spreiten bands is usually <10, and vertical spacing is on the order of 5cm or more.

Teichichnus occurs near the base the Lower Limestone at several localities (e.g. Muzzle Stream). Because of its much younger age (Mangaorapan), and occurrence above the Teredo Limestone, the Lower Limestone *Teichichnus* zone is almost certainly not the lateral correlative of a similar zone (of Teurian age) which occurs above the Lower Chert Member in the Mead Hill Formation (see Chapter 4.1).

Rare *Thallasinoides* and Clavigellid bivalve tubes are sporadically distributed throughout the lower part of the Lower Limestone.

Age

The Lower Limestone ranges in age from mid Waipawan to Mangaorapan (Figure 2.1.2). The base of the Formation is oldest near the depocentre at Mead Stream, and becomes progressively younger southward. The unit wedges out at Bluff Stream where the base is either uppermost Waipawan or lowermost Mangaorapan (Appendix I). From Bluff Stream, the top of the Formation increases in age northward and at the depocentre is mid Mangaorapan. There are no exact age determinations for the unit north of Mead Stream. However, isopach distributions and ages derived from the overlying Lower Marl suggest that a similar but northward younging wedge extends in that direction.

Facies Interpretation

Very little paleoenvironmental data from the Lower Limestone was obtained. The sparse foraminiferal evidence indicates an outer shelf to bathyal environment (Appendix I). The existence of a paleoslope cannot be determined on the limited evidence, but lack of slumping may indicate that only very gentle paleoslopes, if any, existed.

Water depths, especially those to the south of the depocentre, appear to have been considerably greater than those during Mead Hill Formation deposition. Paleogeographic reconstructions (Wilson 1956; Stevens & Suggate 1978) indicate that the (NE-trending) shoreline had transgressed westward between the Haumurian and the Waipawan. Several factors might explain this transgression, including both eustatic sea level rise and basin subsidence. The chronostratigraphic wedge formed by the Lower Limestone (e.g. Figure 2.1.2) indicates that the Formation was deposited during a transgressive-regressive cycle. A eustatic sea level rise might be invoked to explain the post-Teredo Limestone transgression. However, the global curves of Vail et al. (1977) show a static or slight rise in sea level during the period of Lower Limestone accumulation (Figure 7.11).

Isopach patterns suggest that active basin subsidence, centred around Mead Stream, was continuing during Lower Limestone sedimentation. Because the eustatic rises are inferred to have been only slight, it is likely that this latter factor was the dominant influence in the basal transgression.

Its age (Waipawan), stratigraphic position (above the Mead Hill Formation), and relatively high clastic component suggest that the Upper Chert Member is coeval with the oldest part of the Teredo Limestone. It would be difficult not to draw parallels between the Lower Chert Member of the Mead Hill Formation and the Upper Chert Member of the Lower Limestone. Both are interpreted to represent offshore facies equivalents of unconformities developed nearer the basin edge. Both Members pass laterally into their respective sandy facies in the vicinity of Branch Stream.

At its thickest point (i.e. Mead Stream), 78m of calcilutite-dominated pelagic, deep water sediments were deposited over a period probably not exceeding 3m.y. These figures equate to a minimum (compacted) sediment accumulation rate of c.26mm/1000 years.

4.4 Lower Marl (Formation)

Name And Definition

Fergusson (1985) first introduced the name Lower Marl to replace "*Lower Bentonite*" of earlier usage, in order to eliminate genetic connotations. Apart from this name change, no other additions or amendments to the earlier definitions were made. Hall (1964), and later Prebble (1976), defined the unit as being conformably bounded by the Lower Limestone below and the Middle Limestone above.

The Lower Marl consists of cm-m thick, light greenish grey, poorly indurated, micritic, smectite mudstones or marls interbedded with 1-10cm thick, light greenish grey, well indurated, micritic limestones.

The Lower Marl is upgraded in status from Member (Hall 1964, Prebble 1976) to Formation because of its thickness (see below), continuity and regional extent.

Synonomy

The Formation has only been known as Lower Bentonite or Lower Marl (see Figure 2.2.1).

Distribution And Thickness

The areal extent of the Lower Marl is similar to that of the Lower Limestone, although the Formation extends some 10-15km further south (Fig 4.4.1). The maximum recorded thickness (115m) of Lower Marl occurs at Mead Stream. However, the isopach distribution suggests that the depocentre is probably located some 5km to the south, between Limburn and Dee Streams. South of the Hope Fault, the unit is present at Kaikoura, but does not extend as far south as Haumuri Bluff or Monkey Face. In more inland exposures, the isopach pattern varies significantly from that of either the Mead Hill Formation or the Lower Limestone. At least 50m of Lower Marl is present at Limestone Hill, and 10m at Seymour Stream.

Although the overall depositional pattern was broadly similar to that of the preceding Lower Limestone, the depocentre had migrated southward. A secondary depocentre or embayment was probably located near Limestone Hill. The NW-trending, trough-like overall basinal configuration was probably maintained.

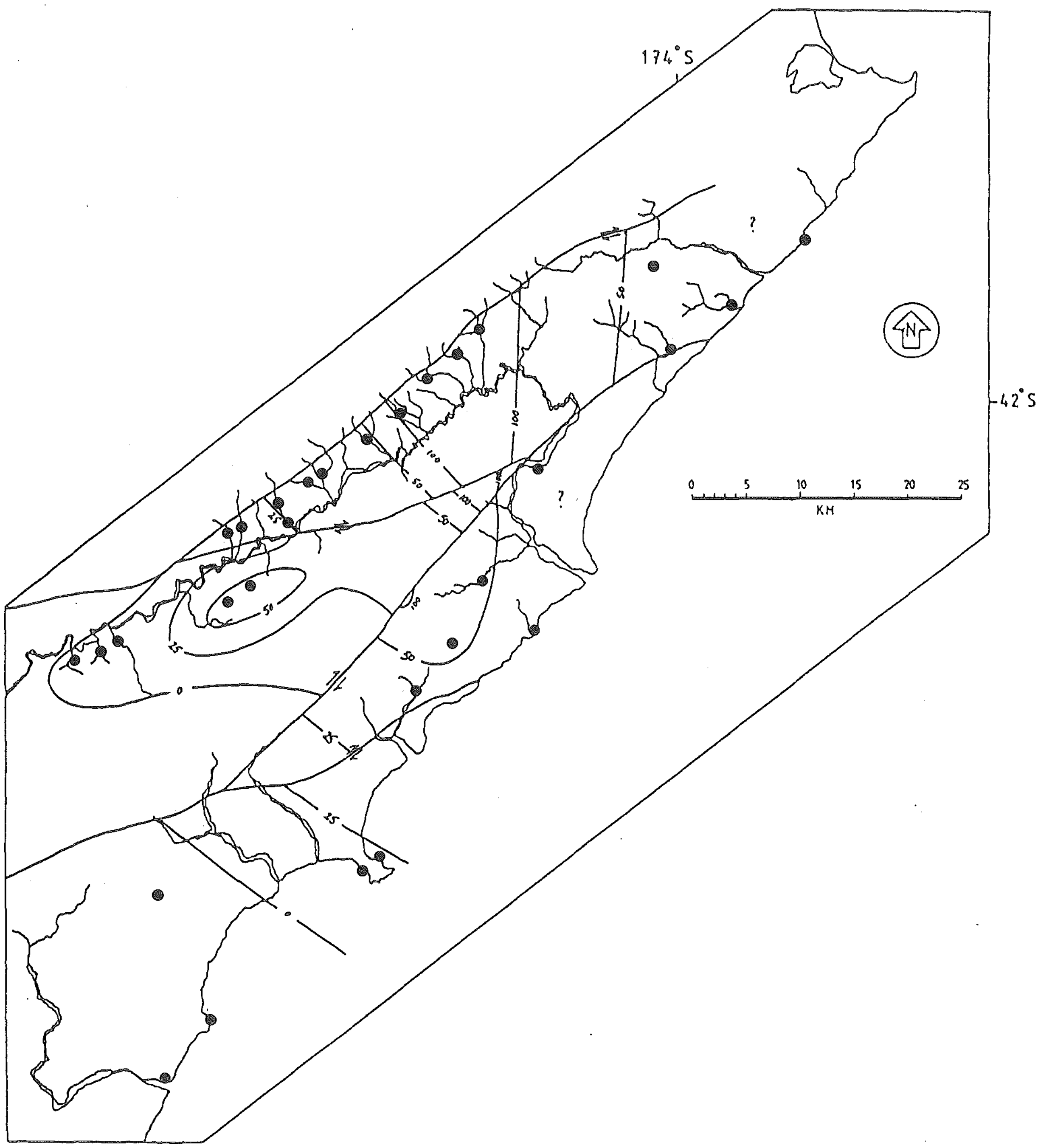


Figure 4.4.1: Paleoisopach map for the Lower Marl. Contours in metres.
Location of measured sections shown in Figure 4.1.1.

Relation To Underlying Rocks

The Lower Marl conformably overlies the Teredo Limestone to the SW of Bluff River (inland) and Kaikoura (coast). The basal contact in these areas is relatively sharp, although very minor quantities of sandy detritus and glauconite persist into the basal few metres of Lower Marl.

North of Bluff River, the Formation conformably overlies Lower Limestone. The relationship of the Lower Marl to underlying units in the northern parts of the study area is unclear but is inferred to be similar to that in the south.

Type Section

Prior to this thesis, a stratotype for the Lower Marl had not been defined. The type section extends from the conformable and gradational contact with the underlying Lower Limestone at S35/078448 up to the conformable contact with the Middle Limestone at S35/077449 in Mead Stream (Appendix IV: JM 30). At that location, the Lower Marl consists of 115m of interbedded dcm-m thick marls and cm-dcm thick micritic limestones.

Lithology

The Lower Marl consists of a sequence of rhythmically interbedded marls and calcilutites, of which marls comprise at least 25%. The thickness and number of marls generally increases symmetrically from the top and bottom of the Formation toward the middle (Fig 4.4.2 & Figs. 2.7, 2.12 in Fergusson 1985).

Until Fergusson's (1985) geochemical study, the Formation was always described as bentonitic (e.g. Prebble 1976). This view was held primarily because of the swelling properties of the wet marl. The Lower Marl is poorly exposed in many areas because of large scale earthflows and slips which have obscured the outcrop. Fergusson (1985) concluded that, on the basis of clay mineralogy and geochemistry, the Lower Marl is not bentonitic in the volcanic sense (e.g. Schultz 1963). Although apparently not derived from in situ alteration of volcanic ash, a secondary volcanic origin of the smectite clay fraction should not be discounted (see discussion in Chapter 7). However, usage of the term smectite mudstone or marl should be continued to avoid genetic connotations.

Apart from minor quantities of detritus near the base, the only sandy lithologies occur in the lower gorge of Woodside Creek where the Formation is overlain by basic lavas of the Woodside Formation (Figure

Figure 4.4.2: View looking north at the north wall of the gorge in Swale Stream, showing Lower Marl underlain by Lower Limestone and overlain by Middle Limestone. Lower Marl is approximately 100m thick.

Figure 4.4.3: Base of Lower Marl. Mead Stream (S35/078448).

4.4.2

4.4.3

4.4.5). Intercalated 1-10cm thick, glauconitic, graded, foraminiferal calcarenites are relatively common at that location in the uppermost 10m of Lower Marl (Appendix IV: JM 104). No other evidence of internal primary sedimentary structures within either marls or calcilutites was discovered. Boundaries between the two lithotypes are usually very sharp.

The biogenic composition of the Lower Marl is approximately the same as that of the Lower Limestone. The micrite fraction is coccolith-derived and the largest allochems are foraminifera.

The range of $CaCO_3$ values varies between 68-75% for calcilutites and 42-73% for marls (Appendix II). The lowest carbonate values for both lithotypes are found near the middle of the Formation (see also Fergusson 1985).

The insoluble residue consists of quartz + illite + smectite ± cristobalite ± clinoptilolite ± barite (Appendix II). The quartz content of the non-carbonate fraction in calcilutites (c.70%) is consistently higher than that of marls (c.40%) (Figure 4.1.14). Fergusson (1985) recognized a large proportion of chert in the sand fraction in the insoluble residue of the Lower Marl. It is possible that the chert may be authigenic rather than detrital. Smectite is the main clay mineral in both lithotypes and predominates over illite by a ratio of 4:1. There is no consistent difference in this ratio between marls and limestones. The amount of barite in the insoluble residue, although usually only comprising c.1% (max: 14%), is consistently higher in limestones than in marls (Appendix II).

Paleontology

The only macrofossils collected from the Lower Marl are two specimens of *Propeamussium* (Figure 4.5.8) which were recovered from near the top of the Formation. The foraminiferal component is greater than 90% planktonic.

Ichnology

Trace fossil preservation in the Lower Marl is extremely poor in both marls and limestones. The intensity of bioturbation appears to be very low on the basis of the visible structures. Scattered *Planolites* and very rare *Zoophycos* were observed near the base of the Formation at several locations. The lack of other primary sedimentary structures suggests the degree of bioturbation may have been originally high but that diagenetic processes have erased individual traces.

Age

The Lower Marl ranges in age from late Waipawan to early Heretaungan (Appendix I). The age of the top of the Formation appears to be almost isochronous throughout the study area. The base of the Lower Marl has a more complex chronostratigraphic pattern. Deposition of Lower Marl commenced in late Waipawan times near Muzzle Stream and Woodside Creek (upper gorge). From these two locations, the base of the Formation becomes progressively younger toward the depocentre at Mead Stream where the Lower Marl did not begin to accumulate until mid Mangaorapan times (Figure A2). South of Muzzle Stream, the base of the Formation becomes younger and at Seymour Stream is Heretaungan in age.

Facies Interpretation

Because the primary difference between the Lower Marl and the Lower Limestone is only the ratio of marl:limestone, a similar paleoenvironment is likely. Foraminiferal assemblages suggest water depths equivalent to modern bathyal conditions. The presence of *Propeamussium*, which is typically found at outer shelf to bathyal depths (J. Crampton, NZGS, pers. comm. 1986), reinforces this view. The genus is also indicative of a very low energy environment.

The Lower Marl is interpreted to represent a pelagic facies deposited during a regressive-transgressive cycle. This interpretation is based mainly on the younging trend from Woodside Creek (in the north) and Muzzle Stream (in the south) away from the depocentre, which presumably represented the deepest part of the basin. Between Muzzle Stream and Seymour Stream, the Formation did not begin to accumulate until later because of either non-deposition and/or erosion associated with the sub-Teredo Limestone unconformity in those regions.

A regressive-transgressive cycle can also be inferred from the stratigraphic variation in marl content. Marls, irrespective of whether they are primary or diagenetic in origin (see Einsele 1982; Ricken 1985, 1986; Hallam 1986), probably reflect an increased input of terrigenous detritus. The most obvious method of producing an influx of very fine clastics (if the smectite can be considered detrital) is by shoreline regression. A fall in sea level promotes increased onshore erosion and leaves rivers unhampered by estuaries. Such conditions would lead to an increase in the sediment supply to the pelagic environment and a consequent dilution of the pure carbonate production.

Conversely, rising sea level leads to the formation of coastal estuaries, which are effective sediment traps. Estuaries are particularly efficient at trapping clay particles, which form the bulk of the non-carbonate fraction of the Lower Marl. From these considerations, the symmetrical increase in the percentage of marl toward the middle of the Formation (indicating an increasing, then decreasing supply of sediment) points to a regressive-transgressive sequence. It is likely that peak of regression occurred during deposition of the marl-dominated middle part of the Formation. At Mead Stream, this part of the Lower Marl is very close to the Mangaorapan-Heretaungan Stage boundary. Significantly, the global sea level curves of Vail et al. (1977) show a major eustatic regression at that time, separating Supercycles T_a and T_b.

At the depocentre, 115m of sediment accumulated over a period not exceeding 3Ma (Figure 1.2: mid Mangaorapan to mid Heretaungan). These figures correspond to a minimum (uncompacted) accumulation rate for the Lower Marl of at least 38mm/1000 years. This figure is c.50% higher than that for the Lower Limestone and can be accounted for by an increased clay supply superimposed on a constant rate of carbonate production.

4.4a Woodside Formation

Name And Definition

The Formation was first named and described from outcrops in Woodside Creek by Prebble (1976) who described it as "*300 feet of graded bedded sandstone and mudstone and bands of massive sandstone*".

The unit is defined here as dcm-m thick, yellowish grey, poorly indurated, graded, sandstones or coarse siltstones interbedded with cm-thick, mudstones and 1-5m thick, massive, weathered tuffs and rare basaltic lavas.

Because of its conformable association with the Lower Marl (albeit an anomalous facies), the Woodside Formation is provisionally placed within the Amuri Limestone Group.

Synonomy

Lensen (1962) described the Formation as "*graded-bedded sandstone and tuffaceous mudstone of Waipawan age*".

Distribution And Thickness

The Woodside Formation is restricted to a strip (<1km wide) immediately west of the Flags Creek Fault between Woodside Creek and the Ure River (Figure 1.5). Within this strip, much of what Prebble (1976) mapped as Cookson Volcanics is reinterpreted as the volcanic facies of the Woodside Formation.

Poor exposure and lack of suitable marker horizons make the total thickness difficult to accurately measure. A maximum thickness of c.150m is estimated for the Formation in Woodside Creek.

Relation To Underlying Rocks

The basal sedimentary contact of the Woodside Formation is exposed only in Woodside Creek (Figure 4.4.5). At that location, a 2m thick basalt flow is underlain by approximately 50cm of dcm-bedded tuffaceous mudstone which rests on Lower Marl. There is little evidence that the contact is unconformable or faulted and the age of the Lower Marl at that location (late Waipawan to Mangaorapan) is not significantly older than the overlying Woodside Formation.

Figure 4.4.4: Flysch facies of Woodside Formation. Woodside Creek (lower gorge). S36/336478. Hammer near centre for scale.

Figure 4.4.5: Lava flow at base of Woodside Formation overlying Lower Marl. Woodide Creek (lower gorge). S36/336478.

4.4.4

4.4.5

Type Section

The type section suggested by Prebble (1976), and accepted here, lies 100-300m downstream of the lower gorge in Woodside Creek and extends from the base of the lava flow at S36/336478 some 150m up to the faulted upper contact with Torlesse Supergroup sandstones at S36/341468.

Lithology

The sedimentary facies consists of a flysch-like sequence of very fine sandy, non-calcareous, subfeldsarenites (Appendix III: JM 200/1) and non-calcareous, micaceous mudstones. Although intercalated with massive tuffs, the sandstones have only a very small detrital volcanic component.

Internal structures within sandstones include well developed Bouma sequences. Little evidence of bioturbation is recognized. Apart from planktonic foraminifera (S36/f829) in the intercalated mudstones recorded by Prebble (1976), and a microfloral assemblage (P30/f2), the Woodside Formation has so far proven unfossiliferous.

Although several thin sections were examined, no attempt was made at a detailed petrographic study of the volcanics with the Formation. All volcanics appear to be basaltic extrusives and no intrusives were observed. Volcanics are the most voluminous lithology and although the base of the Formation is a lava flow, sandstones tend to be restricted to the lower parts of the Formation.

Age

From the limited micropaleontological evidence, the age of the Woodside Formation is constrained to between late Heretaungan and early Mangaorapan (S36/f625, S36/f829, P30/f2). This age shows that the Formation is coeval with parts of the Lower Marl to the west and south.

Facies Interpretation

No direct paleoenvironmental data with respect to depth is available for the Woodside Formation. The conformable contact with underlying bathyal marls and the presence of dominantly planktonic foraminifera may support a deep marine environment. This environment is consistent with a turbiditic origin for the sandstones.

The presence of basalt flows suggests that the volcanic source was near to the site of deposition. It is suggested that the sandstones were deposited from turbidity currents, which were generated at considerable distance from the site of volcanism, during the early extrusive phases. Earthquakes associated with contemporaneous volcanic activity have been invoked as mechanisms for turbidite generation in ancient flysch basins (Rupke 1976; Morris 1983). The flysch-dominated phase was either succeeded or diluted by a voluminous influx of tuffs.

It is difficult to reconcile such a high energy environment with the presence of nearby coeval sediments (Lower Marl) that were clearly being deposited in an extremely low energy regime on a sea floor with negligible slope. Turbiditic sandstones, in particular, would be expected to locally interfinger with the adjacent marls. An unusual sedimentary model would be required to explain this abrupt juxtaposition of facies.

Prebble (1976) resolves this problem by invoking syn-depositional faulting 1-2km west of the Woodside Formation. His main evidence for contemporaneous movement is rapid changes in the age and thickness of individual units within the Amuri Limestone. Further investigation has shown that many of his correlations, especially in the lower gorge of Woodside Creek, are invalid (Appendix IV: JM 104). Only the Woodside Formation, and the thin sequence of Lower Marl below it, are anomalous in comparison with the coeval succession of Amuri Limestone.

It is more likely that the package of Woodside Formation, together with the underlying slice of Lower Marl, are part of an allochthonous infaulted block. To account for the observed facies changes, such a fault would probably require lateral displacement on the order of tens of kilometres. Further detailed work on the nature of the relationship between the Woodside Formation and the Amuri Limestone is warranted. The available data (Chapter 6; Appendix III) is insufficient to allow more specific statements about a possible source for the non-volcanic flysch facies.

4.5 Middle Limestone (Formation)

Name And Definition

The name Middle Limestone was introduced by Hall (1964) to describe "*hard, white argillaceous limestone with rare lenticular flint nodules ... in beds three inches thick that weather into plates ... conformably overlain by Upper Bentonite*" in the upper gorge of Swale Stream.

The Middle Limestone is defined here as 1-10cm stylobedded, white, very well indurated, micritic limestones (NE of Oaro and Limestone Hill) or 1-10cm thick, very light grey, well indurated, micritic limestones interbedded with 1-10mm thick, light greenish grey, poorly indurated, micritic, smectite mudstones or marls (SW from those areas). The boundary between Middle Limestone and Lower Marl is arbitrarily placed at the highest intercalation of marl. The Fells Greensand and Grass Seed Volcanics Members are locally intercalated within the upper part of the Formation.

The Member status attached to the unit by previous authors is upgraded to Formation, because of lateral continuity and thickness.

Synonomy

To the north of Limestone Hill, the Formation has always been known as Middle Limestone. In the Seymour Stream-Limestone Hill area, the informal names "bedded limestone" and "basal limestone" were applied by Reay (1980) and Fergusson (1985) respectively. At Haumuri Bluff, Hector (1874) described the unit as "*Chalk Marls*" and later McKay (1877) applied the name "*Lower Limestone*".

Distribution And Thickness

The Middle Limestone extends throughout the study area as far north as Blue Mountain Stream (Figure 4.5.1). The style and intensity of deformation (see later) particular to the Formation makes it difficult to accurately measure thicknesses at many locations. Although broadly similar to that of the underlying Formations, the Middle Limestone isopach pattern is more complex. Isopachs generally trend NW and are inferred to close to the SE.

In contrast with the earlier deposited units (e.g. Mead Hill Formation, Lower Limestone), the Middle Limestone in the vicinity of Mead Stream is relatively thin. South of Limburn Stream, the Formation

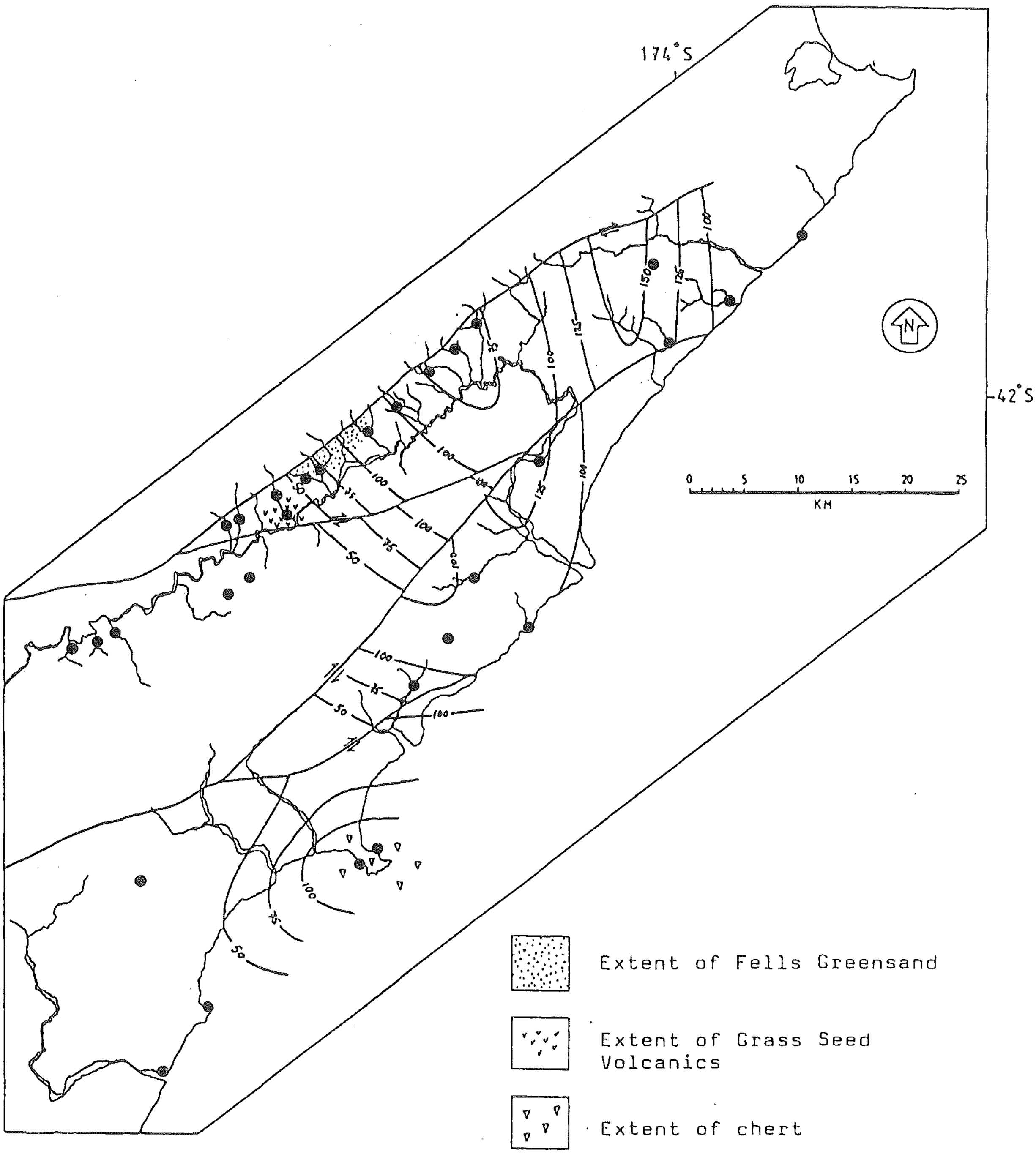


Figure 4.5.1: Paleoisopach map for the Middle Limestone. Contours in metres. Location of measured sections shown in Figure 4.1.1.

thickens to a local maximum of c.140m at Dart Stream, and thins rapidly further south. The unit thickens to the north of Mead Stream, and at Isolation Creek is inferred to exceed 150m. Because intense deformation precludes section measurement, this estimate is based largely on huge outcrop thicknesses and isopach trends which show the Formation thickening towards this area.

An anomalously thick sequence of Middle Limestone is present at Kaikoura. Although the degree of internal deformation is greatest at this location, an accurate thickness (100m) was determined. Individual chert-bearing limestone beds are continuous over several hundreds of metres. Careful correlation and structural logging of these chert horizons allowed a true thickness to be calculated. Closure of the positive area around Kaikoura is inferred on the basis of the lack of fit with the regional pattern and the anomalously high volume of chert. The Formation thins southward from Kaikoura, and at the mouth of the Conway River is c.40m thick. The isopach pattern NE of Woodside Creek is unknown, but it is likely that the unit thins very rapidly in that direction.

Relation To Underlying Rocks

The base of the Middle Limestone is conformable everywhere, except at Monkey Face. At that location, the Teredo Limestone (which underlies the Middle Limestone nearby) is only preserved in burrows, and the Formation rests unconformably on Woolshed Formation (see Crampton 1985). South of Kaikoura, the Middle Limestone overlies Teredo Limestone; from Kaikoura north, the Formation overlies Lower Marl.

Wellman (1959, p135) states that the Teredo Limestone at Haumuri Bluff, "... *is separated from the base of the Amuri* (Middle Limestone) *by a well defined erosion interval*". At that location, the contact between Teredo Limestone and the Middle Limestone is in fact gradational over c.10cm and therefore conformable (see also Warren & Speden 1978).

Type Section

The type section for the Middle Limestone extends from the conformable contact with the Lower Marl at S35/076450 up to the conformable contact with the Upper Marl at S35/075452 in Mead Stream (Appendix IV: JM 30). At that location, the Formation consists of 75m of 2-5cm stylobedded, white, well indurated, micritic limestone. The sequence is devoid of interbedded marls.

Reference Section

Haumuri Bluff (S56/812733 - 813733)

The Formation comprises approximately 31m of 5-10cm thick, light grey, well indurated, micritic limestones interbedded with 2-50mm thick marls conformably overlying Teredo Limestone (Appendix IV: JM 15). Marls increase in thickness upwards and the Formation is transitional into the overlying Upper Marl. Stylobedding is not developed in this section.

Lithology

The three main features which lithologically distinguish the Middle Limestone (from Kaikoura north) from the rest of the Amuri Limestone Group are: the absence of interbedded marls; the presence of stylobedding; and the style of deformation.

With the exception of very rare beds near the middle of the Formation, and minor intercalations near the bottom and top, marls are absent from the stylobedded facies of the Middle Limestone (Figure 4.5.2). The lack of marls may be directly related to the development of stylolites. The regular vertical spacing and parallelism to bedding may suggest that stylolites mimic bedding planes (Logan & Semeniuk 1976). If thin (1mm or less) marls were originally present (as they are in the southern facies at Haumuri Bluff), then a process of diagenetic unmixing (e.g. Hallam 1986; Ricken 1986) may have accentuated primary differences in carbonate to the extent that stylolites replaced the marls.

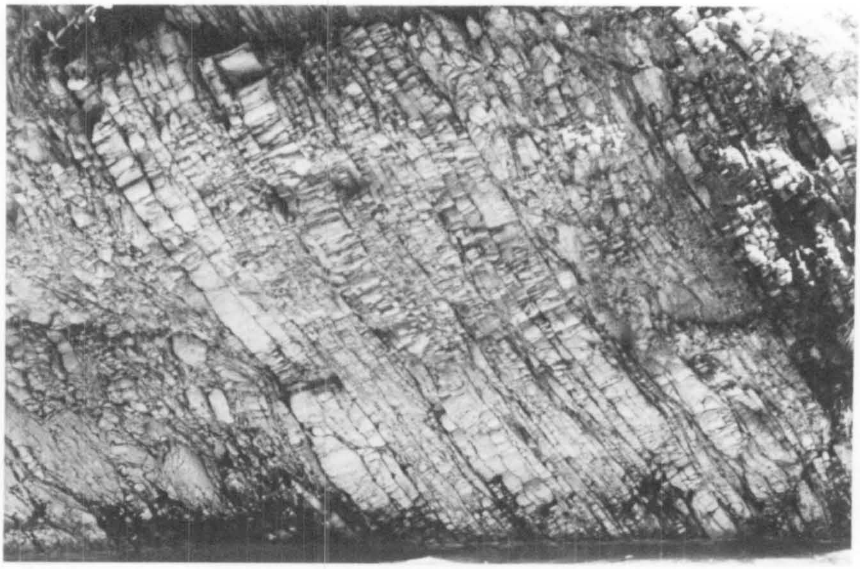
The structural fabric within the Middle Limestone is dominated by m-scale kink folds, which at Kaikoura have been shown to be related to km-scale NE-trending folds (J.K. Campbell, University Of Canterbury, pers. comm. 1987) of post-Oligocene age. In thicker sequences of Middle Limestone near Isolation Creek and the Ure River, this phase of deformation is synchronous with similar scale disharmonic folds reported by Prebble (1980). There is no evidence that these small scale folds are related to soft sediment slumping, as suggested by Waterhouse & Bradley (1957) and Prebble (1980). This type of deformation is entirely restricted to the Middle Limestone and almost certainly reflects its high degree of anisotropy (e.g. Figure 4.5.2) and lack of internal surfaces suitable for flexural slip folding (Dewey 1965). Assuming stylolites developed prior to the kink folding event, the interlocking nature of stylolitic surfaces would have impeded flexural slip.

Figure 4.5.2: Stylobedded facies of the Middle Limestone. Hammer for scale. Ure River.

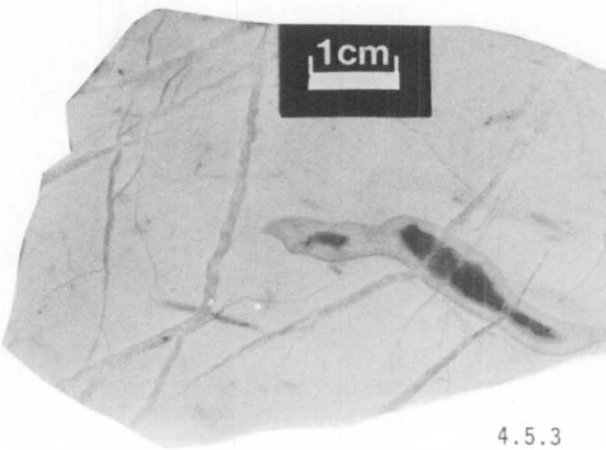
Figure 4.5.3: Polished slab of stylobedded Middle Limestone containing small chert nodule. Note absence of bioturbation.

JM 30/35 12271 Mead Stream S35 077449

Figure 4.5.4: View of stylobedded chert-rich Middle Limestone at Kaikoura. Scale = 20cm. *Photo: M. Lawrence.*



4.5.2



4.5.3

4.5.4

Another feature of the Formation which distinguishes the Formation from the rest of the Amuri Limestone is its very pure composition in comparison with other calcilutites throughout the Group. The Middle Limestone averages c.90% $CaCO_3$ (Appendix II & Figure 4.1.13), which is at least 10% higher than that of limestones from the overlying and underlying Formations. This relative purity may, in part, be attributable to the degree of stylolitization and/or diagenetic unmixing.

The insoluble residue consists of quartz + smectite ± illite ± cristobalite. XRF analysis shows that the non-carbonate fraction has a total of c.90% SiO_2 which equates to c.77% modal quartz. Smectite is the dominant clay mineral.

Petrographically, the limestone is a fossiliferous micrite; the only allochems being poorly preserved foraminifera. SEM studies show that the Middle Limestone (the stylobedded facies, in particular) is composed almost entirely of recrystallized micrite. Although only visible as very rare "ghosts", coccoliths are inferred to have been the main source of the micrite fraction (G.J. van der Lingen, NZGS, pers. comm. 1985). Glauconite and detrital sand are virtually absent from the stylobedded facies, except where the Formation is in contact with the Fells Greensand.

No internal sedimentary structures were observed in the Middle Limestone. The pink colouration mentioned by Prebble (1976) actually describes the upper part of the Mead Hill Formation at Woodside Creek.

Very rare, small chert nodules (Figure 4.5.3) are scattered throughout the Formation in most places, but are most concentrated at Kaikoura Peninsula. Nodules there, are generally restricted to anomalously thick (>10cm) beds (Figure 4.5.4) that can be correlated over large distances. Up to 25% of the rock is replaced by chert in three distinct zones located 23-28m, 41-50m, and 57-69m respectively, above the base of the Formation (see Appendix IV: JM 1).

South of Kaikoura (and Limestone Hill), the Middle Limestone has a quite different character (see Figure 4.2.11). Kink folding is absent; interbedded very thin marls separate calcilutites; the lithology is less pure than to the north; and the stylobedding, which is a ubiquitous feature elsewhere, is not present. In this southern facies, marls increase in thickness upwards and the upper 10-20m of the Formation is relatively sandy, containing up to 5% very fine sand size glauconite and detritals.

Paleontology

The only macrofossil found in the stylobedded facies of the Middle Limestone was a small, indeterminate, poorly preserved bivalve or brachiopod in Dart Stream (Figure 4.5.9). In the well-bedded facies at Oaro, pectins and echinoid spines (identified as *Prionocidaris* aff. *marshalli* by J. Crampton, NZGS) are relatively common near the sandy upper part of the Formation (Figure 4.5.10-11), in association with large silicified *Thallasinoides* burrows. Foraminifera, which usually comprise c.1-2% of the sediment, are almost exclusively planktonic.

Ichnology

Recognizable trace fossils are absent from the stylobedded facies of the Middle Limestone, except in direct association with the Fells Greensand Member (e.g. Figure 4.6.15). Near Haumuri Bluff, rare Clavigellid bivalve tubes are present near the base of the Formation. In the same area, branching networks of chert nodules, exposed on bedding planes near the top of the Formation, are interpreted to represent silicified *Thallasinoides* burrow systems (Figure 4.5.5-6). These nodules are typically flattened, have a maximum diameter of 10cm, and extend laterally up to 5m. Burrows generally terminate at 120° triple junctions. Similar silicified *Thallasinoides* systems have been described by Bromley & Ekdale (1984b). These authors relate the chertification process to factors such as increased porosity, permeability and organic content of the burrow fill.

The silicification margin surrounding burrows is generally very sharp (Figure 4.5.7). In most cases, the burrow fill contains thin horizontal lenses of pyrite, which indicate a high organic content. In contrast to the absence of bioturbation structures in the surrounding limestone, silicified burrows have an internally well developed secondary ichnofabric. Secondary trace fossils, including small *Thallasinoides* and *Chondrites*, are restricted to the burrow system and do not extend into the surrounding sediment.

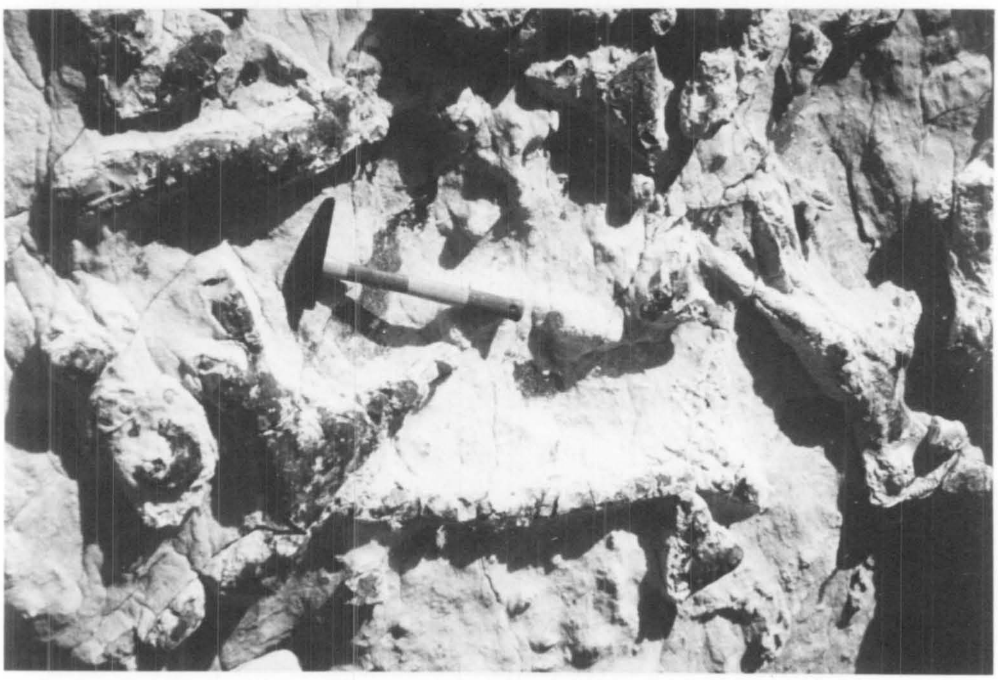
Ekdale & Bromley (1984b) have shown that certain deeply burrowing ichnofauna (e.g. *Chondrites*) prefer to colonize older burrow systems. It is uncertain whether the internal ichnofabric of the silicified *Thallasinoides* burrows at Oaro is related to primary factors (e.g. the

Figure 4.5.5: Plan view of small (1-2cm diameter) silicified *Thallasinoides* burrows. Shore platform south of Oaro (S56/802773). *Photo: G.J. van der Lingen.*

Figure 4.5.6: Plan view of large (5-10cm diameter) silicified *Thallasinoides* burrows. Shore platform south of Oaro (S56/802773). *Photo: G.J. van der Lingen.*

Figure 4.5.7: Section view of large silicified burrow in Figure 4.5.6. Sharp silicification rim at base extends outside burrow wall. Concentrations of pyrite define back-fill spreiten. Note secondary burrowing by smaller *Thallasinoides* and *Chondrites*.

4.5.5



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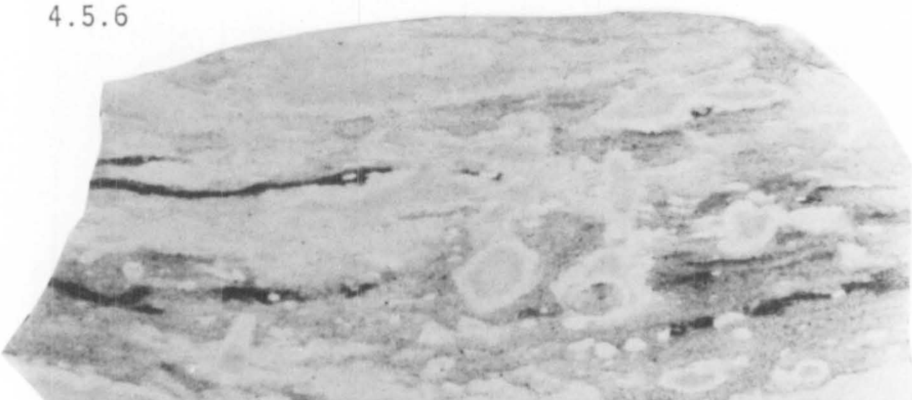


4.5.7

increased organic content or porosity of the burrow fill) or to enhanced preservation due to silicification. Because similar, though unsilicified *Thallasinoides* burrows in the overlying Upper Marl Formation display an anomalously high degree of internal bioturbation (Figure 4.6.6), the former alternative is more likely.

Age

Because foraminifera are extremely difficult to extract from the stylobedded facies of the Middle Limestone, the age of the Formation is based largely on samples from the highest and lowest intercalated marls from the underlying and overlying units. Anomalous marls occurring nearer the centre of the Formation have been utilized wherever possible. The well bedded southern facies is relatively productive in terms of extractable microfauna.

The Middle Limestone varies in age from Mangaorapan to Bortonian. Because of the large thickness (50m or more) of overlying Bortonian age Upper Marl in most areas, it is unlikely that the top of the Middle Limestone is anywhere (in Marlborough) younger than mid-Bortonian. The oldest parts of the Formation occur south of Kaikoura, at Haumuri Bluff and Conway River (Appendix I), where the base is Mangaorapan. The difference in ages between the top of the Teredo Limestone (Waipawan) and the conformable base of the Middle Limestone (Mangaorapan) at Haumuri Bluff can be accounted for if either: i) the Teredo Limestone is late Waipawan and the base of the Middle Limestone is early Mangaorapan; or ii) the Teredo Limestone contains reworked microfauna. The former alternative is supported by the age of the Teredo Limestone (early Mangaorapan) at nearby Conway River mouth.

North of Haumuri Bluff, the contact between the Lower Marl and Middle Limestone appears to be isochronous (Figure 2.1.2). However, because the age of the boundary is only constrained to within the Heretaungan Stage, as much as 2m.y. of variation is possible.

Variation in the age of the top of the Formation is more complex. The youngest age determination (Porangan) is from the base of the overlying Upper Marl in The Fell. From a total of c.250 age determinations for the Amuri Limestone Group in Marlborough, this sample has provided the only definite Porangan date. Although the Porangan is relatively short (<2m.y.) in comparison with the other New Zealand Paleogene Stages (Figure 1.2), this paucity of determinations probably confirms that in

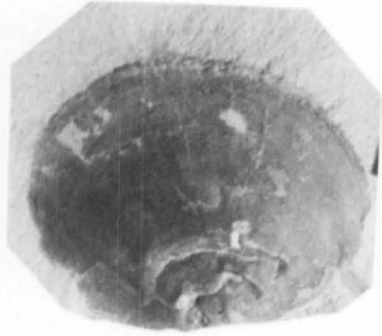
Figure 4.5.8a,b: Specimens of *Propeamussium* from Lower Marl. Same scale for both specimens.

Figure 4.5.9: Poorly preserved bivalve or brachiopod from Middle Limestone. Dart Stream (S42/968340).

Figure 4.5.10: Indeterminate pectins from Middle Limestone at Oaro (S56/802773).

Figure 4.5.11: Echinoid spines (*Prionocidaris* aff. *marshalli*) from Middle Limestone at Oaro (S56/802773).

4.5.8a



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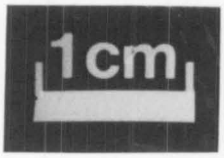

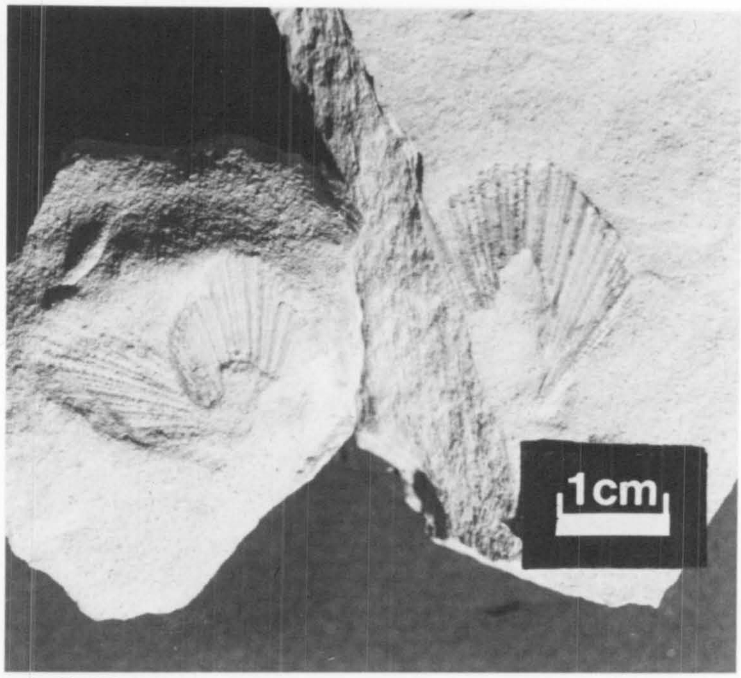

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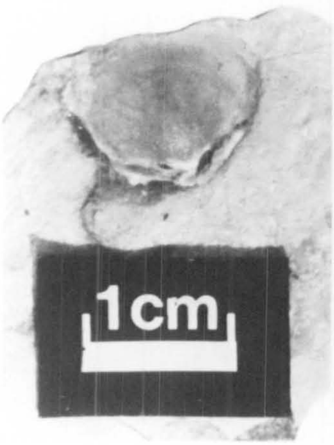

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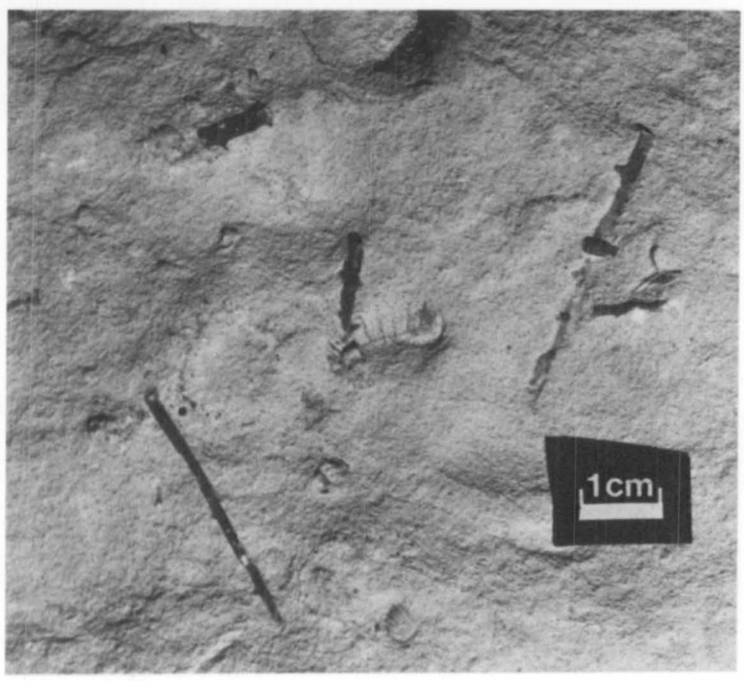


4.5.11

Marlborough the Stage is almost entirely confined within the Middle Limestone.

Elsewhere, the age of the top of the Formation fluctuates within the early part of the Bortonian Stage. The specimens of *Prionocidaris* aff. *marshalli*, associated with large *Thallasinoides* at Oaro, have been dated as Bortonian. Foraminifera from the same horizon provide a similar age but include reworked Mangaorapan to Heretaungan fauna (O32/f25).

Between Dead Horse Gully and Dart Stream, minor intercalations of the Fells Greensand Member (discussed in detail later in this Chapter) are present in the upper part of the Middle Limestone. Several km to the south, in Bluff Stream, greater thicknesses of Fells Greensand are intercalated within the Upper Marl. At both locations, the Fells Greensand is estimated to be early to mid-Bortonian in age (O30/f134, O30/f126).

Facies Interpretation

Apart from foraminifera, the Middle Limestone is virtually devoid of useful paleoenvironmental indicators. The overwhelming predominance of planktonic foraminifera indicates oceanic conditions equivalent to modern bathyal depths. This interpretation is consistent with those of the enclosing Formations. The relatively high carbonate content indicates deposition in an environment of much reduced clastic input.

The absence of stylobedding in the southern facies probably results from a higher detrital clay content in the primary sediment. Thicker intercalated marls may have had an inhibiting effect on the stylolitization process. Conversely, the degree of stylolitization and relative purity of the northern facies almost certainly indicates that if intercalated marls were ever deposited, they were either very thin or more calcareous than those to the south.

The southward trend of increasing thickness of marls and decreasing carbonate content of limestones in the Middle Limestone is in agreement with the inferred provenance of clastics. This trend continues into North Canterbury where the less calcareous Ashley Mudstone was deposited (Browne & Field 1985). Evidence that a shoreline existed c.100km to the SW of the study area, during deposition of the Middle Limestone, can be found in coeval deposits (Homebush Sandstone) in North Canterbury (Browne & Field 1985). The Homebush Sandstone has been interpreted as a fluvial deposit by Carlson et al. (1980).

The association of large *Thallasinoides* burrows with anomalous macrofossils in a relatively sandy lithology near the top of the Formation at Oaro and Haumuri Bluff, suggests a hiatus of early to mid Bortonian age (Appendix I). Evidence provided by reworked foraminifera at this horizon indicates the presence of increased current activity. *Thallasinoides* burrows elsewhere in the Amuri Limestone are almost exclusively related to significant periods of non-deposition. The paucity of benthic macrofossils throughout the Amuri Limestone can be attributed to unsuitable substrate conditions. The presence of macrobenthics may therefore be an indication of at least firm substrates. Although there is no evidence for hardground formation, a break in sedimentation may have allowed surficial sediment consolidation (or early cementation?). The coincidence of a minor influx of detritals with this diastem is unlikely to have been accidental and may indicate the presence of a significant hiatus.

4.6 Upper Marl (Formation)

Name And Definition

The name Upper Marl was introduced by Fergusson (1985), replacing "Upper Bentonite", to avoid the genetic implications of this earlier term. Hall (1964) first described the unit as "*graded bedded, hard, white, argillaceous, limestone and soft bentonitic mudstone in bands six inches thick*".

The Upper Marl is defined here as massive, light greenish grey, poorly indurated, micritic, smectite mudstone or marls with minor intercalated 1-5cm thick, light grey, well indurated, micritic limestones.

Because of its regional extent and thickness, the unit is best considered as a Formation. The Grass Seed Volcanics and Fells Greensand Members are commonly intercalated within the Formation.

Synonomy

MacPherson (1948, 1952) described the unit in the Kekerengu River as the "*Benmore Group*". Hall (1964) and Prebble (1976) both adopted the usage "*Upper Bentonite*". Lensen (1978b) used the name "*Benmore Bentonitic Shale*".

Distribution And Thickness

The Upper Marl extends throughout the field area at least as far north as Blue Mountain Stream (Figure 4.6.1). North of that area, the unit is either very thin and not exposed, or it is not present.

The effects of erosion on its upper surface make it difficult to construct a paleoisopach map for the Upper Marl. The wide spacing of available data points in relation to the amount of differential erosion would render isopach lines meaningless.

The only comment that can be made with respect to the regional thickness of the Upper Marl is that it is probably at its thickest (120m) near Mead Stream. The minimum recorded thickness (27m) occurs at Dead Horse Gully. North of Mead Stream, thicknesses were not measured because of the lack of structural control.

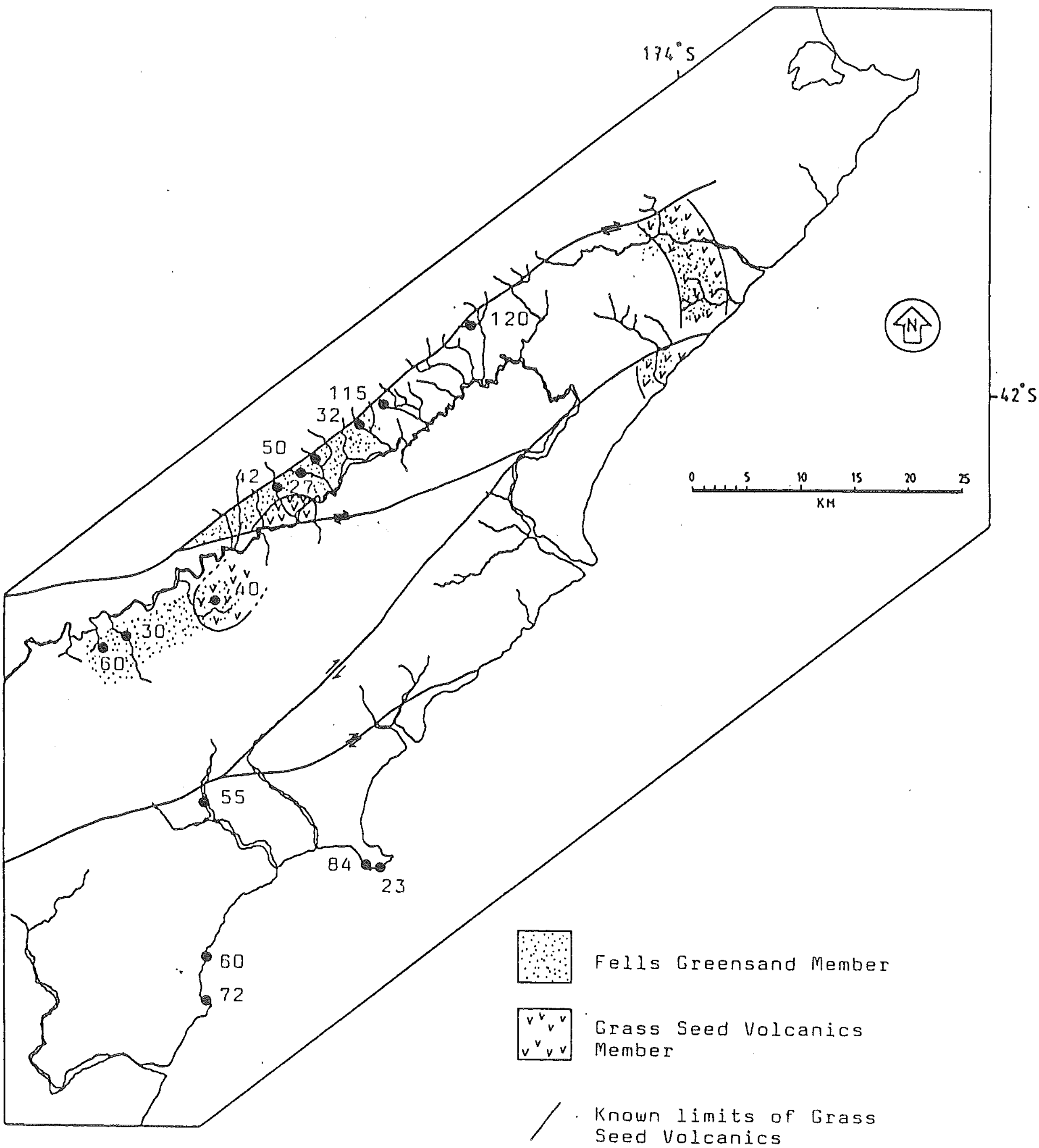


Figure 4.6.1: Actual thicknesses of Upper Marl, also showing extent of intercalated Fells Greensand and Grass Seed Volcanics.

Relation To Underlying Rocks

The Upper Marl conformably overlies the Middle Limestone and the lower contact is arbitrarily set at the base of the lowest intercalated marl.

Type Section

The type section established here for the Upper Marl extends 120m up from the contact with the Middle Limestone at S35/076450 up to the unconformable contact with the Weka Pass Stone at S35/075452 in Mead Stream (Appendix IV: JM 30).

Lithology

In most areas, the Upper Marl cannot be easily distinguished from the Lower Marl on the basis of lithology alone. Stratigraphic position and age constraints are usually required to discriminate between the two Formations. The principal differences include: a lower volume of intercalated limestone; a slightly sandy lithology in some areas; the presence of minor quantities of very fine carbonaceous material; and a slightly deeper green colouration in the Upper Marl.

Whereas the Lower Marl contains at least minor volumes of interbedded limestone throughout, the Upper Marl contains c.50m thick sequences which are completely devoid of limestone. In further contrast with the Lower Marl, interbedded limestones are not rhythmically distributed, except near the base, where the contact is usually gradational over 10-20m (Figure 4.6.2). Limestone-rich stratigraphic packages (c.10m) occur randomly throughout the Upper Marl (Figure 4.6.3). Even within these intervals, the thickness of limestone rarely exceeds 30% of the total.

Although not ubiquitous, very fine sand sized detritus and glauconite is a relatively common component. In those sequences where there are no intercalations of Fells Greensand, the amount of sand is usually not greater than a 1-2% percent. A well rounded pebble (1cm) of indurated sandstone was extracted from the lower part of the Formation at Kaikoura. This clast is interpreted as a rafted dropstone.

Primary sedimentary structures, other than bedding, are not present. The graded bedding mentioned by Hall (1964), Prebble (1976) and Fergusson (1985) was not observed. It is assumed that this feature, if present, is related to the Fells Greensand.

In Woodside Creek, a single 30cm bed of red marl is intercalated within the Formation. It is assumed that this horizon is a distal correlative of similar, thicker sequences in nearby Blue Mountain Stream, interbedded within the Grass Seed Volcanics.

The only significant compositional difference between marls and limestones occurs in their respective $CaCO_3$ contents (Figure 4.1.13). Marls vary between 48-83% (mean: 66%); limestones range through 66-84% (mean: 77%) (Appendix II). Within the limits of experimental error, the insoluble residues of both lithotypes have the same composition (Figure 4.1.14). The non-carbonate fraction has a modal composition of quartz + smectite ± illite ± clinoptilolite ± kaolinite ± barite. Quartz, smectite and illite generally comprise >98% of the insoluble residue and are present in the approximate ratio (Q)50: (S)40: (I)10. The other components, where present, only occur in very minor quantities.

Both marls and intercalated limestones are texturally mudstones. The micrite fraction, although intensely recrystallized in most cases, is presumed to be coccolith derived. Very well preserved foraminifera, although generally in the range of 1-2%, commonly comprise up to 5% of the sediment. Finely comminuted carbonaceous material is a ubiquitous component and preliminary analysis indicates the presence of at least 2% C_{org}.

The bentonitic nature of the Upper Marl was originally suggested by MacPherson (1952), on the basis of chemical analysis, association with volcanics and the frequency of large earth flows (e.g. Blue Slip) derived from the Formation. Fergusson (1985) has since shown that, like the Lower Marl, the dominant lithotype within the Upper Marl is better described as a smectite mudstone or marl. Morris (1986) infers that the association with landslides is related as much to large scale faults, which preferentially use the Formation as a convenient slide medium, as to the swelling and/or flowing properties of the lithology.

Paleontology

In comparison with the rest of the Amuri Limestone, the Upper Marl contains a relatively abundant macrofauna. It should be emphasized that macrofossils are nevertheless, extremely rare and in the majority of sections examined none were observed.

At Kaikoura, a number of poorly preserved, indeterminate oysters, a

Figure 4.6.2: Transitional base of Upper Marl showing interbedded marls and calcilutites. Mead Stream (S35/076450).

Figure 4.6.3: Limestone-rich stratigraphic package of Upper Marl at Mead Stream (S35/075452). Unconformable contact with Weka Pass Stone at top, right. Figure at bottom, left for scale. *Photo: M. Lawrence.*

Figure 4.6.4: Indeterminate (?*Planolites* (P)) exichnia within the red marl facies of the Upper Marl.

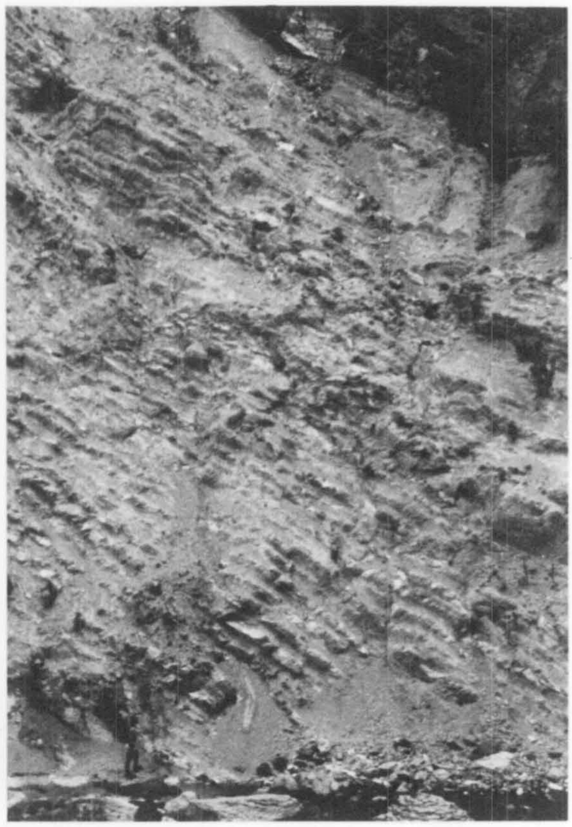
JM 104/15 12332 Woodside Creek S36 299467

Figure 4.6.5: Partially pyritized crinoid stem from near the base of the Upper Marl.

Figure 4.6.6: Large *Thallasinoides* burrow near top of Upper Marl at Kaikoura (S49/968885). Note backfill spreiten and secondary ?*Chondrites* burrows in a C_{org}-rich burrow fill.

Figure 4.6.7: *Terebratulid* brachiopod from Upper Marl at Kaikoura (S49/877975).

4.6.2



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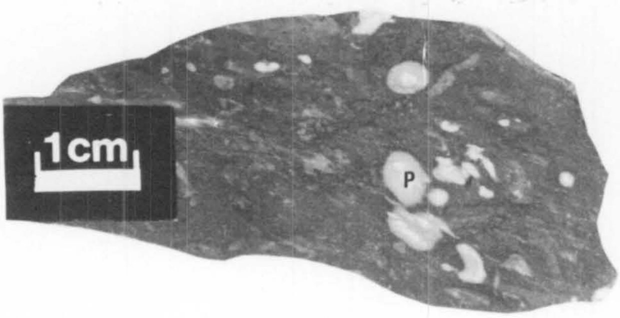

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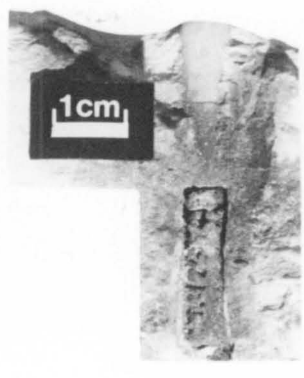

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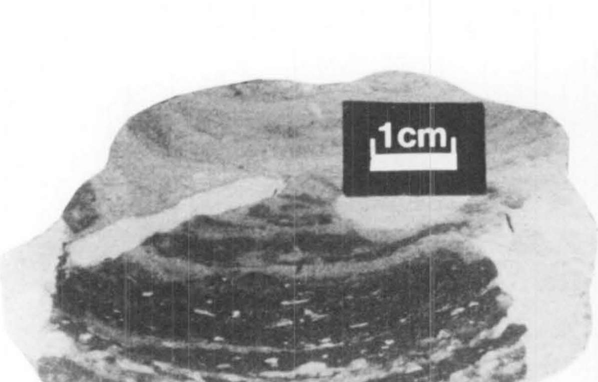

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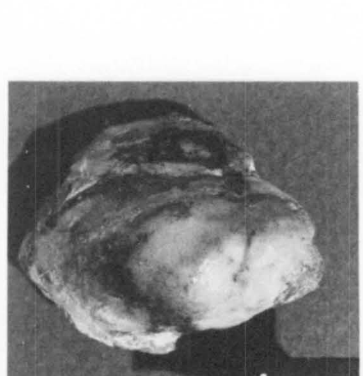


4.6.7

single *Terebratulid* brachiopod, and a small cetacean bone were recovered from the Upper Marl (Figure 4.6.7). At Oaro, a partially pyritized crinoid stem was extracted from near the base of the Formation (Figure 4.6.5). Foraminifera comprise an average of c.75% planktonic species.

Ichnology

Except on weathered bedding surfaces, trace fossils are difficult to recognize throughout the bulk of the Formation. Plan views of *Zoophycos* are relatively common in relief but are usually undetectable in section. Near the top of the Formation, large (>5cm) diameter *Thallasinoides* burrows, infilled with dark grey marl (Figure 4.6.6), may be related to the overlying unconformity. Indeterminate (?*Planolites*) exichnia are commonly visible within red marls, because of their lighter coloured burrow fill (Figure 4.6.4).

Age

The age of the Upper Marl is well constrained in most areas, and ranges between Porangan and Runangan (Appendix I). As mentioned earlier the Porangan date (O31/f145) in The Fell is anomalous and elsewhere, the base of the Formation falls within the upper half of the Bortonian Stage. The age of the top of the Formation (and the Amuri Limestone Group) is entirely controlled by the effects of an angular unconformity (see Chapter 6). The youngest known age (O32/f31) is late Runangan (latest Eocene). The oldest ages from immediately below the overlying unconformity are Bortonian. Those sections where the age of the top of the Formation is youngest also contain the greatest thicknesses.

Facies Interpretation

On the basis of analysis of the foraminiferal population, deposition took place in an oceanic environment. Water depths were probably comparable with those in modern outer shelf to bathyal settings (Appendix I). The paleoenvironment, in terms of bathymetry, is unlikely to have been greatly different from that of the underlying Formations.

A high organic content can be inferred from the amount of carbonaceous material. It is reasonable to assume that the nutrient content was high enough to support a burrowing infauna. Biogenic homogenization may therefore account for the apparent lack of bioturbation. Furthermore, intense bioturbation might explain the paucity of intercalated limestones which may have been mixed and diluted with marls. The presence of *Zoophycos* makes it probable that other shallower burrowing organisms were also active. The high detrital and organic content (relative to the Lower Marl) may account for the increased numbers of benthic macrofossils. These constituents may have helped to create a substrate with a somewhat firmer consistency. The ability of the sediment to support a more numerous epifaunal community than throughout the rest of the Amuri Limestone may lend support to this interpretation.

A basin-wide influx of fine clastics resulted in the change from a clay mineral-poor (Middle Limestone) to a clay mineral-rich carbonate ooze (Upper Marl). This change was accompanied, and in some cases preceded by localized deposition of glauconitic quartzarenites (Fells Greensand). The best estimate for the timing of this terrigenous influx is early to mid Bortonian. This influx is coincident with the hiatus recognized near the top of the Middle Limestone at Oaro and Haumuri Bluff, and may be synchronous with a Porangan-Bortonian disconformity recognized in North Canterbury (Browne & Field 1985).

Although the increase in the supply of detritals coincides with a global regression (TE2.1-TE2.2 of Vail et al. 1977), there is evidence that the associated sea level fall was not necessarily the primary cause for clastic dilution. The absolute eustatic change in sea level is minor and superimposed on an overall transgressive phase encompassing the remainder (c.10m.y.) of Upper Marl accumulation (Figure 7.11). The magnitude of the regression at the end of TE2.1 may have been sufficient to induce transportation of shallow shelf sediments (Fells Greensand) into the bathyal setting, but its effects are unlikely to have caused such prolonged clastic dilution.

It is more likely that regional, rather than global, factors influenced the facies change. Because no significant difference in water depths between the Upper Marl and the earlier deposited Amuri Limestone can be recognized there is little evidence for major basinal uplift. The pulse of volcanism recorded in late Bortonian times (Grass Seed Volcanics) indicates at least minor contemporaneous tectonism. Tectonic activity, either closer to shore or onland, may have provided increased volumes of sediment without necessitating a major regression.

4.6a Fells Greensand (Member)

Name, Definition, And Synonomy

The name Fells Greensand was originally given by Hall (1964) to describe "*massive, finely laminated, hard, greensand*" interfingering with Upper Marl east of Coverham.

The unit is defined here as intercalated laminated, greenish grey, well indurated, calcite cemented, glauconitic, fine to medium sandy, quartzarenites within the uppermost Middle Limestone or Upper Marl. The unit is considered to be a Member within each of these Formations.

The Member has always been known as Fells Greensand (Prebble 1976; Fergusson 1985).

Distribution and Thickness

The areal distribution of the Fells Greensand is shown in Figure 4.6.1. The Member is restricted to an inland southern area between Seymour and Dart Streams and to a northern area which extends from Kekerengu to the Ure River. The sandy, uppermost part of the Middle Limestone at Oaro (Appendix IV: JM 3 & Chapter 4.5) is coeval with, and occupies a similar stratigraphic position, to the Fells Greensand. On this basis, the interval is correlated as a facies equivalent.

The unit varies in thickness from a single 5cm thick bed to numerous 10-20cm thick beds intercalated throughout a 20m interval (Figure 4.6.9). The maximum recorded thickness for any individual bed is c.2m for a lens at Woodside Creek.

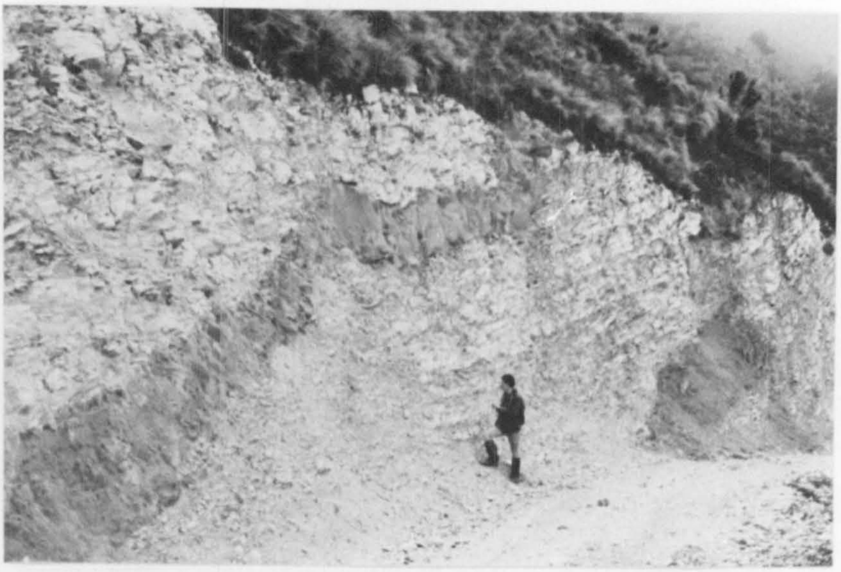
Type Section

The type section for the Fells Greensand Member is 11.4m thick and extends from 3.5m above the base of Upper Marl in Bluff Stream at S42/875275 (Figure 4.6.9; Appendix IV: JM 50B). The limits of the section coincide with the lowest and highest intercalation of glauconitic quartzarenite. Individual beds are 5-25cm thick, normally graded, laminated and have abundant sole markings (e.g. flute casts, *Thallasinoides* in hyporelief). Intervening marls are sandy, glauconitic, massive, and contain moderate numbers of exichnial *Thallasinoides*.

Figure 4.6.8: Sandstone dikes intruding Upper Marl near Mt. Alexander (S42/070150).

Figure 4.6.9: Intercalated Fells Greensand in Upper Marl. Bluff Stream (upper) (S42/875275). Bed immediately right of pack corresponds to stratigraphic position 5m in type section (Fig 4.6.11).

Figure 4.6.10: Hummocky cross-stratified lens of Fells Greensand. Marfells Beach (S29/475720).



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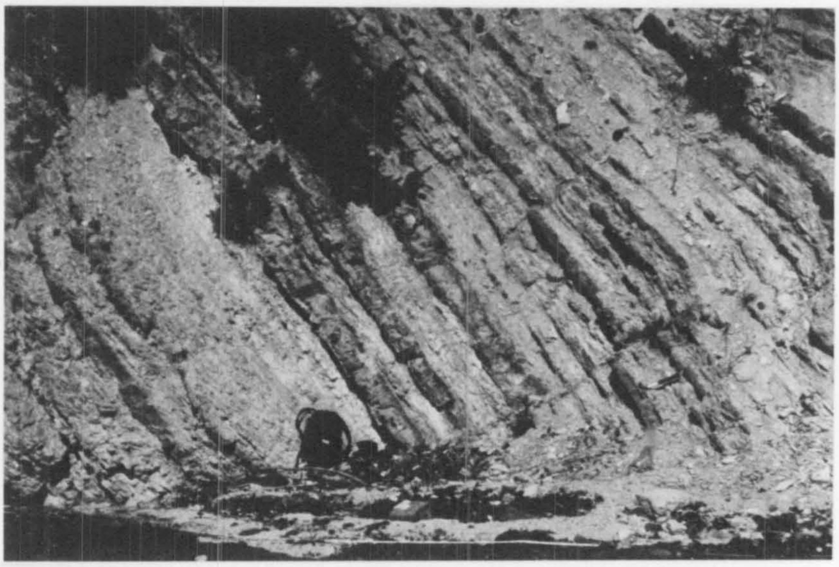

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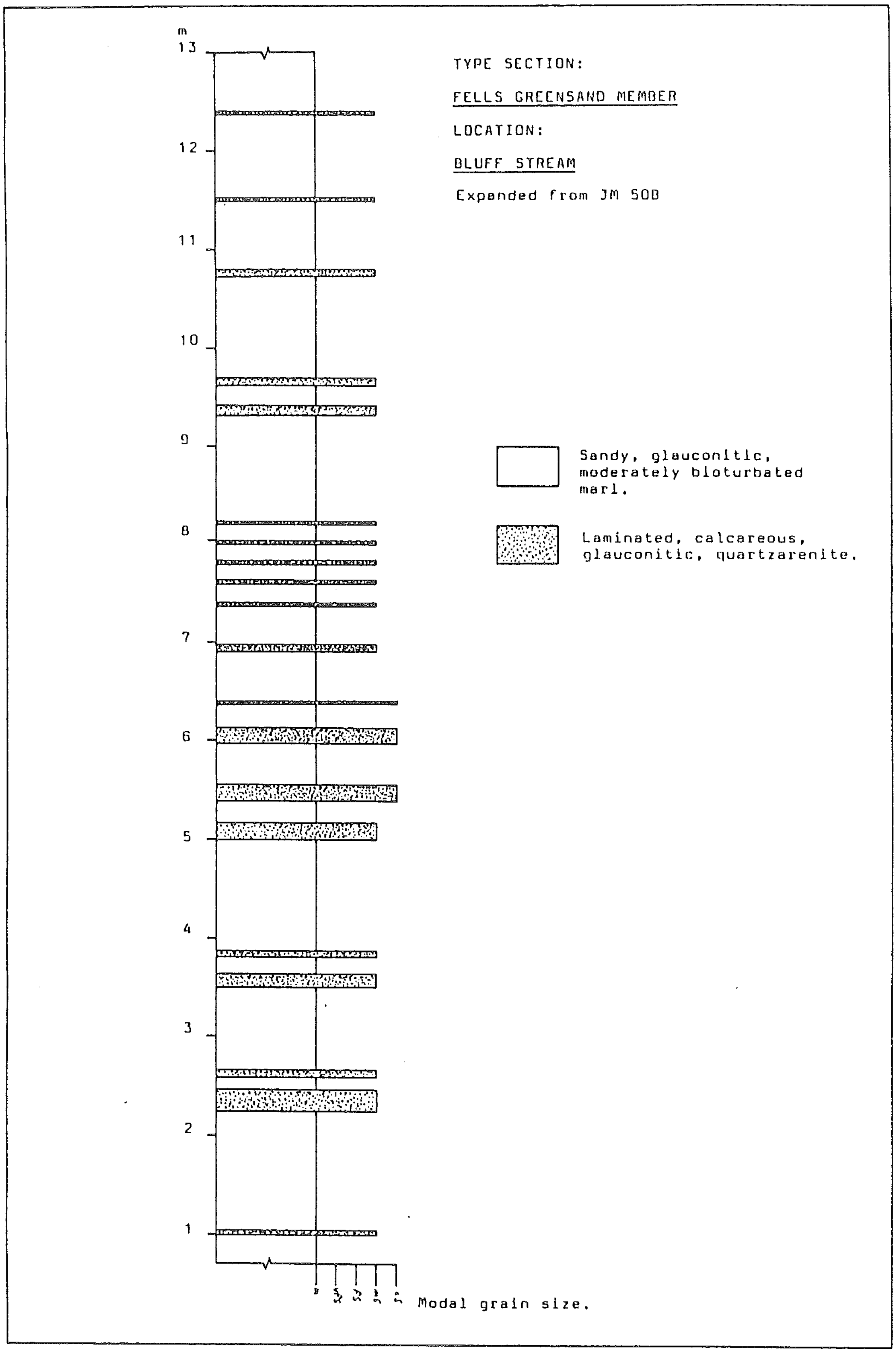


Figure 4.6.11: Type section of Fells Greensand Member. Bluff Stream (upper) (S42/875275).

Lithology

The petrography of the Fells Greensand is outlined and discussed in Chapter 6.3. The unit is most commonly represented as a sequence of one or more cm-dcm thick sandstone beds intercalated within marl or calcilutite. The total thickness of interbedded sandstone rarely constitutes more than 25% of the overall stratigraphic thickness. Individual beds cannot be traced between outcrops and thicker beds (i.e >1m) are characteristically lensoidal in outcrop (Figure 4.6.10).

Flute casts are rarely preserved on the sole of beds but these are commonly distorted by the effects of loading (Fig 4.6.17). Internal sedimentary structures may include a massive basal interval overlain by laminations (concentrations of glauconite) and/or normal grading. Probable hummocky cross-stratification (Figure 4.6.10) is entirely restricted to a single outcrop at Marfell's Beach in the northernmost part of the study area. Geographic isolation, uncertain structural relations, and lack of age control makes correlation of these northern beds with the southern facies questionable.

The Fells Greensand has so far proven unfossiliferous.

Ichnology

Thallasinoides burrows (1cm diameter) are the only ichnotaxa associated with the Fells Greensand. The most common mode of preservation is as passively infilled exichnia within the underlying lithology (Figure 4.6.15) or as hypichnial casts on the base of beds. In a rare example, branching networks pass laterally into spiral forms (Figure 4.6.16). The degree of bioturbation is greatest at the interface between the sandstone and the underlying marl. Burrows extend 1m or more below the base of a bed and their density decreases downward. Internal bioturbation of sandstones is not obvious but may occur in the basal massive interval. Exichnial *Thallasinoides* much less commonly extend from the sandstone upward into the overlying marl. Such burrows decrease in frequency upward and do not usually occur more than 10cm above the top of the sandstone.

Age

Microfauna extracted from the sediments enclosing the Fells Greensand indicate a early-mid Bortonian age (Appendix I).

Figure 4.6.15: Detailed section view of base of Fells Greensand bed in Middle Limestone. Note *Thallasinoides* exichnia extending down into underlying limestone.

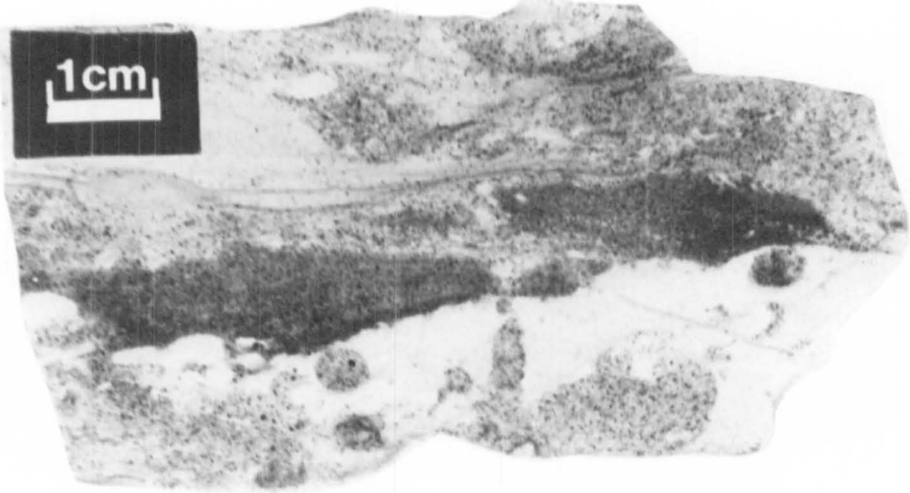
JM 42/7 12293 Dart Stream S42 968341

Figure 4.6.16: Spiralling form of *Thallasinoides*? exposed in hyporelief on base of Fells Greensand bed.

JM 51/2 12319 Gentle Annie Stm S42 827236

Figure 4.6.17: Detail of loaded flute casts on sole of Fells Greensand bed.

JM 300/2 12368 Marfells Beach S36 475723



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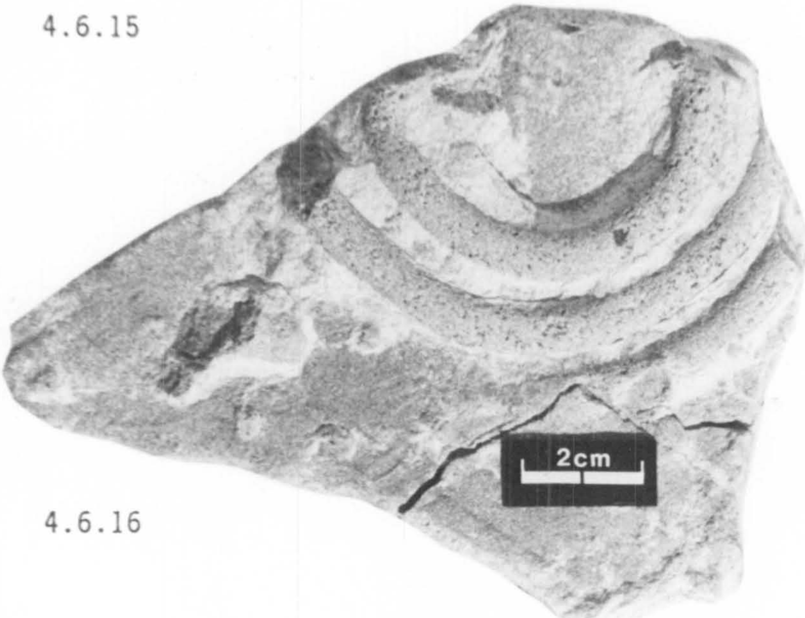

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4.6.17

Facies Interpretation

From textural considerations (Chapter 6.3), and internal sedimentary structures, the Fells Greensand is interpreted as having been deposited from sediment gravity flows. Detrital quartz and glauconite accumulated closer to shore and were transported into the pelagic environment during high energy events.

The lack of internal bioturbation of sandstones, and the passive nature of the burrow fill, suggests that the underlying exichnia were open to the sediment/water interface at the time of sandstone deposition. The relative concentration of burrows on the soles of beds can be explained in several ways. Either the burrows are infilled casts in the underlying marl or they represent the active traces of organisms operating at the sandstone/marl interface.

Because the maximum concentration of *Thallasinoides* occurs at the sandstone/marl interface, the former alternative would require each sandstone to have been deposited onto an omission surface. Because every sandstone has an intensely burrowed base and every burrowed surface is overlain by a sandstone, a genetic relationship between sandstone and omission surface must be demonstrated. The event deposit interpretation placed on the Fells Greensand makes any such relationship unlikely.

Exichnia extending into the overlying sediment may be interpreted as escape structures. This interpretation would require that the overlying marls were deposited very rapidly. Another possibility is that burrows, extending down from the overlying marl, acted as water escape conduits for the sands.

4.6b Late Eocene Sedimentary Dike Suite

A related suite of sandstone dikes intrude the Mead Hill Formation (e.g. Needles Point), Lower Marl (e.g. Mt Alexander), Middle Limestone (e.g. Puhi Puhi River), and Upper Marl (Figure 4.6.8). The petrography of these dikes is discussed in Chapter 6.3. Dikes occur at all orientations with respect to bedding and range in width from 1cm to 1m. Although the detrital composition is similar to that of the Fells Greensand, important textural differences suggest that they do not feed that unit. Cross-cutting relations show that intrusions are at least post-Bortonian in age and are therefore unrelated to either the pre-Claverley

Sandstone or pre-Teredo Limestone dikes. No evidence was found to suggest that the dikes penetrate post-Amuri Limestone sediments. It is suggested that the dikes are synchronous with a phase of deformation recognized beneath the mid Whaingaroan unconformity (see Chapter 5).

4.6c Grass Seed Volcanics (Member)

Name And Definition

The Grass Seed Volcanics were defined by Reay (1980) as "*a sequence of basaltic tuffs and limestones which occur locally within the Amuri Limestone*". This definition is modified and extended to include all volcanics (and their associated intrusives) intercalated within the Middle Limestone and/or Upper Marl.

Synonomy

At Grass Seed Stream, the Member was described as "*Tuff within the Amuri Limestone*" by Suggate (1958). Further north, in the Kekerengu area, MacPherson (1952) described the unit as volcanics within the "*Benmore Bentonitic Shale*" (Upper Marl). Lensen (1962) and Prebble (1976) described these volcanics, and correlatives in the Ure River, as undifferentiated Cookson Volcanics.

Distribution And Thickness

The extent of the Grass Seed Volcanics is similar to that of the Fells Greensand (Figure 4.6.1). In the southern half of the field area, the Member is restricted to a small area surrounding Grass Seed Stream and another, 7km to the NE, in Bluff Stream. The volcanics were probably originally continuous between these localities. The Member also outcrops along an arcuate strip between Kekerengu River and Blue Mountain Stream.

? what is an extrusive tuff ?

Reay (1980) measured a maximum thickness of 160m in Grass Seed Stream, where the upper contact is erosionally truncated. At Bluff Stream, extrusive tuffs are estimated to be c.50m thick. Because of the lack of internal markers and intense deformation, the total thickness of the unit in the Kekerengu - Ure region is difficult to estimate. Prebble (1976) suggested a maximum figure of 800ft (c.250m) near Deep Creek.

The Member is typically lensoidal in character and can thin several hundred metres over 1-2km. In Grass Seed Stream, the 160m thick pile of tuffs thins laterally over 300m into a single 30cm thick basalt flow which is overlain by 1m of tuff. The volcanic pile in the northern area generally thickens toward an area between Blue Mountain Stream and Deep Creek.

Type Section

The type section extends from the conformable contact with the Upper Marl at S42/830191 up to the unconformable contact with the Cookson Volcanics at S42/826187, in Grass Seed Stream (Reay 1980).

Relation To Underlying Rocks

Dikes of tuff and lava feeding Grass Seed Volcanics extrusives are well exposed in Bluff Stream, where tuff has intruded laterally along the contact between Mead Hill Formation and Claverley Sandstone. These vents become extrusive in the upper part of the Middle Limestone or in the lower part of the Upper Marl. At the same location, extrusives are directly underlain by a 1m thick, massive, glauconitic, subfeldsarenitic, very fine sandstone which rests conformably on the Middle Limestone (Appendix IV: JM 50A). At all other localities, the Grass Seed Volcanics are wholly intercalated within the Upper Marl. A cobble to boulder volcanic breccia is intercalated within the Upper Marl at the base of the Grass Seed Volcanics in the type locality (Figure 4.6.21).

Lithology

Most lithologies, especially tuffs, are intensely weathered and calcite and/or zeolite replacement is ubiquitous. Extrusives consist of massive to poorly stratified tuff, cobble breccias, and pillow lavas.

Sandy tuffs, which are the dominant lithotype, commonly contain angular, cobble to boulder size blocks of basalt. Intercalations of pillow lavas, up to 20m thick, are common in Blue Mountain Stream but were not observed elsewhere. Individual pillows have a distinctive knobbly surface texture (Figure 4.6.19). Interpillow sediments consist of well indurated pink micritic limestone or marl.

Intrusive volcanics consist of dikes and sills of tuff and lava, ultramafic sills, and vent breccias. The ultramafics consist of a pyroxenite intrusion, south of Woodside Creek, described by Prebble (1976). A basaltic breccia outcrops at the confluence of Blue Mountain Stream and the Ure River. The interlocking fabric of angular clasts, together with the lack of sedimentary features, suggests that the breccia was fractured in situ and was never eruptive.

Marls associated with tuff in the Kekerengu - Ure area are typically pink to red and contain abundant angular sand to cobble size fragments of tuff, as well as phosphatized limestone clasts (Figure 4.6.20).

Figure 4.6.18: Pillow lavas in the Grass Seed Volcanics, with interstitial micritic limestone sediment. Blue Mountain Stream (S36/267552). Scale = 30cm.

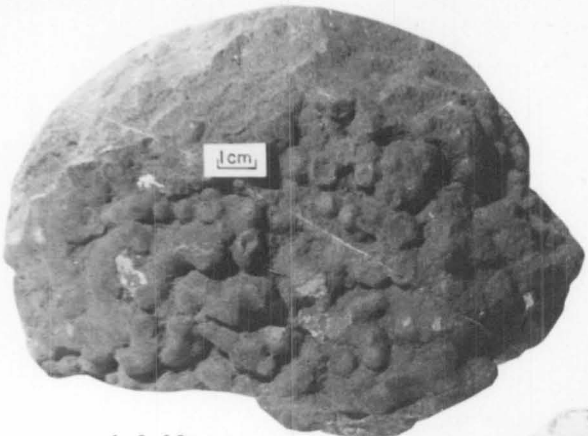
Figure 4.6.19: Detailed view of knobbly surface texture of an individual pillow from Figure 4.6.18.

Figure 4.6.20: Polished slab of intercalated limestone in Grass Seed Volcanics. Blue Mountain Stream (S36/267551). Note abundant scattered angular (coarse sand to granule size) phosphatic lithoclasts.

Figure 4.6.21: Volcanic cobble to boulder conglomerate intercalated in Upper Marl, near base of Grass Seed Volcanics. Grass Seed Stream (S42/830191). Scale = 10cm.

10m ?

4.6.18



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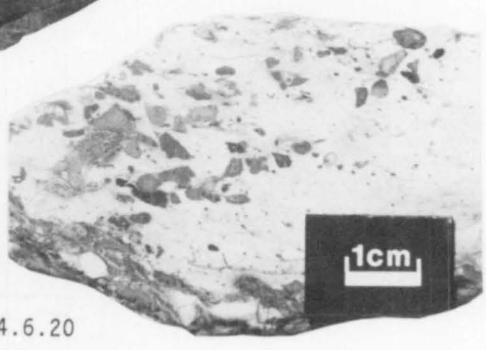


4.6.20

4.6.21

In contrast, a single 1-2m thick marl intercalated near the middle of the volcanics in Grass Seed Stream is devoid of any primary volcanic detritus.

The most significant aspect of the 1m sandstone beneath the extrusives in Bluff Stream, is that it contains no volcanic detritus (Appendix III: JM 50/24), except for rare fragments of tuff imbedded in its upper surface. Although occupying a similar stratigraphic position to the Fells Greensand, its texture and composition are most similar to the Claverley Sandstone (see Chapter 6.2).

Little is known of the petrology of the volcanics. Prebble (1976) described the lavas near Kekerengu as aphyric basaltic andesites.

Age

Foraminifera extracted from marls intercalated within the volcanics at Grass Seed, Bluff, Benmore, and Blue Mountain Streams (Appendix I), provide late Bortonian (c.44Ma) ages. No radiometric ages for the unit are known.

Facies Interpretation

Extrusive basaltic volcanism was apparently localized to two contemporaneous centres during the late Bortonian. Marls intercalated within the volcanics contain foraminifera which are diagnostic of bathyal, oceanic deposits. The presence of pillow lavas confirms subaqueous extrusion.

The intrusive volcanic breccia near the mouth of Blue Mountain Stream is interpreted as a frozen plug within the vent of a submarine volcano. This interpretation is supported by the relative thickness of the immediately surrounding extrusives.

The almost total lack of primary volcanic detritus in coeval sequences of Upper Marl, except within a few km of source, has implications for the general paleoenvironment. Because coarse pyroclastic ejecta are not widespread, volcanism was probably never subaerial or even shallow marine (Macdonald 1972). Very low energy background conditions are suggested by the total lack of reworked or altered volcanic sand size detritus (Fergusson 1985). As suggested by Reay (1980), volcanic conglomerates associated with the unit in Grass Seed Stream (Figure 4.6.21) as well as others in the Ure River, probably represent subaqueous mass flow deposits derived from the slopes of a volcano.

The relationship between Grass Seed Volcanics and the Fells Greensand is not obvious. Where the two are in association, the Fells Greensand underlies or is intercalated near the base of the volcanics. The sediment is clearly not directly derived from the volcanics, because the detrital component of the Fells Greensand is c.95% quartz and has a negligible volcanic content. Tectonic activity, as a precursor to volcanism, may have triggered sediment gravity flows nearer the basin edge. Although feeder dikes have not been discovered, intrusion of remobilized Claverley Sandstone was almost certainly a precursor to volcanic activity at Bluff Stream.

Correlation

The Grass Seed Volcanics are not considered to be correlatives of, or continuous with, the Cookson Volcanics. The age differential (c.14Ma) between the two units, lack of volcanism in the intervening period, and a major unconformity (see Chapter 5) separating them, suggest two distinct episodes of volcanism. Further petrogenetic study would be required to test this statement.

The Otitia Basalt in South Westland (c.330km SW), represents the only known coeval volcanics in New Zealand. This unit is very similar in lithology and age (c.45Ma) to the Grass Seed Volcanics (Nathan 1977; Sewell & Weaver in prep.). In addition, the Otitia Basalt also interfingers with marls and limestones, in a similar manner to the Grass Seed Volcanics (Nathan et al. 1986; Aliprantis 1987).

The oldest known "Waiareka-Deborah volcanics" (Coombs et al. 1986) in North Otago (c.330km SSW) are slightly younger (c.40Ma) than the Grass Seed Volcanics, but appear to be lithologically similar.

Chapter Five

POST-AMURI LIMESTONE STRATIGRAPHY

Introduction

The Amuri Limestone Group in Marlborough, extends up to the unconformity at the base of the Cookson Volcanics or Motunau Groups (Figures 2.1.1 & 2.1.2). This Chapter outlines the nature of the unconformity and describes the stratigraphy of the immediately overlying sediments and their relationship to the Amuri Limestone.

5.1 Phosphatic Conglomerate Bed

Name And Definition

The Phosphatic Conglomerate Bed (PCB) is defined as the thin lag of phosphatized nodules which unconformably overlies the Amuri Limestone in Marlborough. The PCB forms the basal layer of the Cookson Volcanics (where deposited) and Motunau Groups.

Synonomy

Many previous authors have briefly described the PCB in Marlborough e.g.:

Hector (1874):	"a thin layer of brecciated fragments of calcareous greensands"
McKay (1877):	"Green sand conglomerate"
Morgan (1916):	"thin layer of conglomerate formed almost wholly of phosphatized fragments of limestone"
Speight & Wild (1918):	"nodular layer"
Thomson (1919):	"4ft of bright-green glauconitic calcareous sandstone with dark phosphatic nodules"
Suggate (1958):	"worm-bored greensand with phosphatic nodules"
Browne & Field (1985):	"fossiliferous, burrowed, very glauconitic fine to very fine sandstone with phosphatized Amuri Limestone clasts"

Only Armstrong (1972), who applied the name "*Phosphatic Nodule Horizon*", has attempted to treat the unit as formal lithostratigraphic unit.

The unconformity beneath the PCB in Marlborough, has generally been referred to as the "*Marshall Paraconformity*" (Carter & Landis 1972, 1982; Findlay 1980; Browne & Field 1985). Because there is considerable question as to the exact age and stratigraphic relations of the Marshall

? its type area

Paraconformity away from the field area (see Lewis & Bellis 1984; Lewis et al. 1986), further work is required to test the implicit correlation. In fact, several unconformities of similar character and age to that in Marlborough have been shown to exist south of the study area (Lewis et al. 1979; Lewis & Bellis 1984) and it is by no means clear as to which, if any, of these can be correlated northward.

not well (or at all ?) demonstrated ; anyway paracont is everywhere applicable at outcrop level

Relation To Underlying Rocks

The PCB in Marlborough abruptly overlies the Upper Marl Formation of the Amuri Limestone Group. The contact is always unconformable, but only rarely can discordance be detected in outcrop. The maximum known local discordance across the unconformity (c.3°) occurs at Kaikoura (Figure 5.1.2). Although difficult to recognize in outcrop, truncation of the underlying Amuri Limestone is evident on a regional scale (Figure 2.1.2). By definition (ISSC 1987), the surface is an angular unconformity on a regional scale and a disconformity at outcrop scale, and is nowhere in Marlborough a paraconformity.

Fig 2.1.2 doesn't demonstrate this

Variations in thickness of the underlying Upper Marl (100m over 2-3km), which can be demonstrated across Kaikoura Peninsula, cannot be explained in terms of original depositional trends in that unit. No consistent pattern of regional truncation can be recognized and the fluctuations in the age of the upper surface of the Amuri Limestone shown in Figure 2.1.2, essentially reflect the geographic sampling interval.

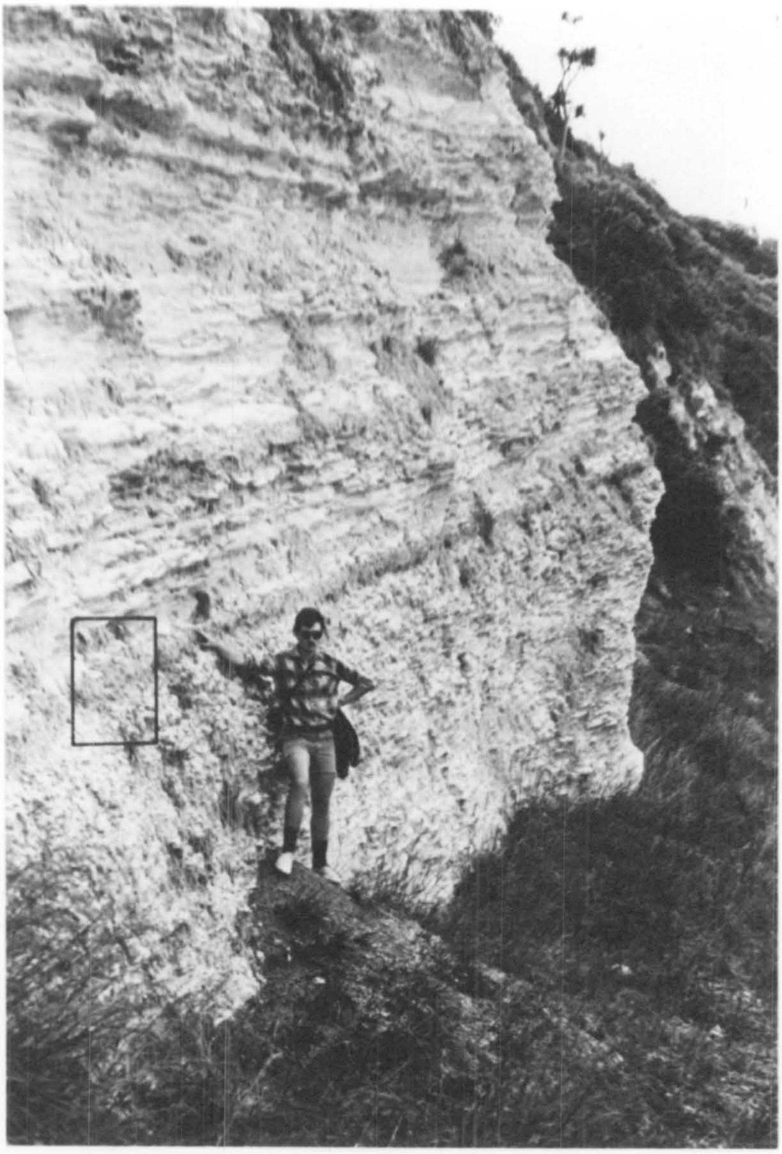
Distribution And Thickness

The PCB forms a remarkably uniform veneer (5-20cm thick), throughout the southern part of the study area. NE of Limestone Hill and Puhi Puhi River, the unit thins and is only represented as sporadic coarse sand to granule size clasts of phosphatized limestone in the basal few cm of Weka Pass Stone.

A layer of similar age and character is widespread outside of the study area and has been recognized throughout Canterbury and further south (Armstrong 1972; Findlay 1980). Armstrong's (1972) correlation of this layer with the PCB in Marlborough is valid only if lateral continuity and/or coeval relationships can be demonstrated.

Figure 5.1.1: View of unconformable contact between the Phosphatic Conglomerate Bed (conformably overlain by Waima Siltstone) and stylolitized Upper Marl (Amuri Limestone Group). Oaro (S56/802775). Hand resting on contact. Note apparent lack of discordance in bedding.

Figure 5.1.2: View of unconformity between the Phosphatic Conglomerate Bed (conformably overlain by Weka Pass Stone) and the Upper Marl (Amuri Limestone Group). Kaikoura (S49/968885).



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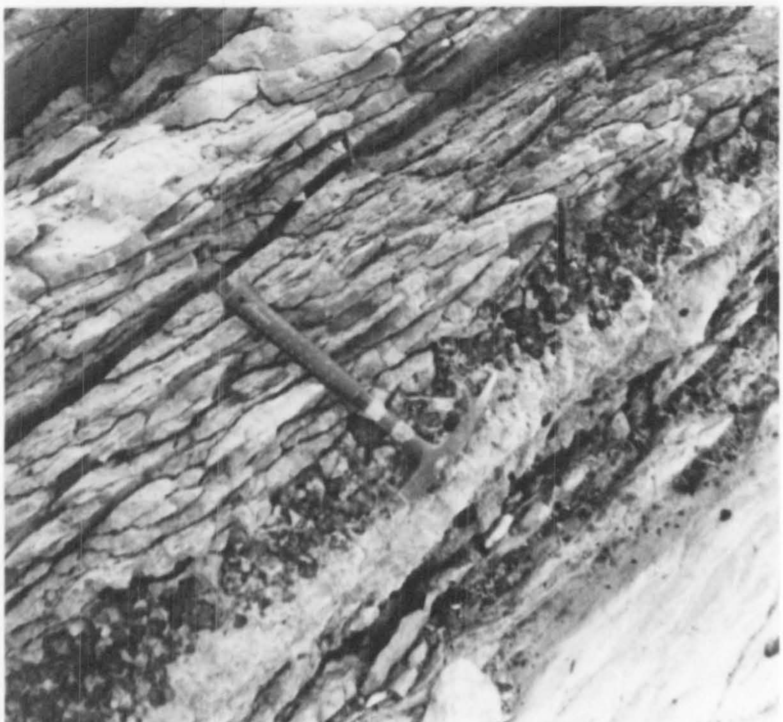


5.1.2

Reference Section

Because of the probable inter-regional extent of the PCB (Carter & Landis 1982), it would be pre-emptive of this study to attempt to formalize a type section. The locality at which the unit is best developed in Marlborough is in the rail cutting c.500m south from the mouth of the Oaro River at S56/802775 (Figure 5.1.1). Here, the PCB extends 20cm above the concordant contact with anomalously well indurated and stylolitized Upper Marl (Appendix IV: JM 3). Moderately sorted, angular clasts (5-50mm) of phosphatized micritic limestone are contained in a matrix of sandy, foraminiferal biomicritic limestone. *Thallasinoides* burrows (1cm diameter) extending into the Upper Marl are passively infilled with the overlying lithology.

Lithology

The PCB is typically composed of angular, phosphatized lithoclasts, rare bivalve and brachiopod casts, cetacean bones, and shark's teeth, set in a matrix similar to that of the overlying sediment (Figure 5.1.4). In an anomalous section in The Fell (Appendix IV: JM 123), phosphatic clasts are enclosed within a 15cm thick foraminiferal packstone which is abruptly overlain by c.20m of fine sandy, basaltic tuff (Cookson Volcanics). At this location, 2m of massive, greenish grey, moderately indurated, calcareous, fossiliferous, glauconitic, very fine to fine sandstone forms the lower part of the PCB. *Thallasinoides* burrows, infilled with limestone, penetrate into the sandstone, but do not extend into the underlying Amuri Limestone.

The clasts are exclusively micritic limestone indistinguishable from the underlying Amuri Limestone (Figure 5.1.6), except for phosphatization, the extent of which ranges from only slight alteration of clast rims through to entire replacement. In general, alteration decreases inward from the clast wall. In situ phosphatization of the upper surface of the Amuri Limestone was not recognized.

At several localities, well rounded granules of quartz, chert, and indurated mudstone are present in minor quantities within the matrix.

Ichnology

The only recognized burrowing ichnotaxa associated with the PCB is *Thallasinoides*, which is ubiquitous. The depth of penetration of exichnia appears to be directly related to the degree of induration of the uppermost Amuri Limestone. At Kaikoura, where the Upper Marl is less

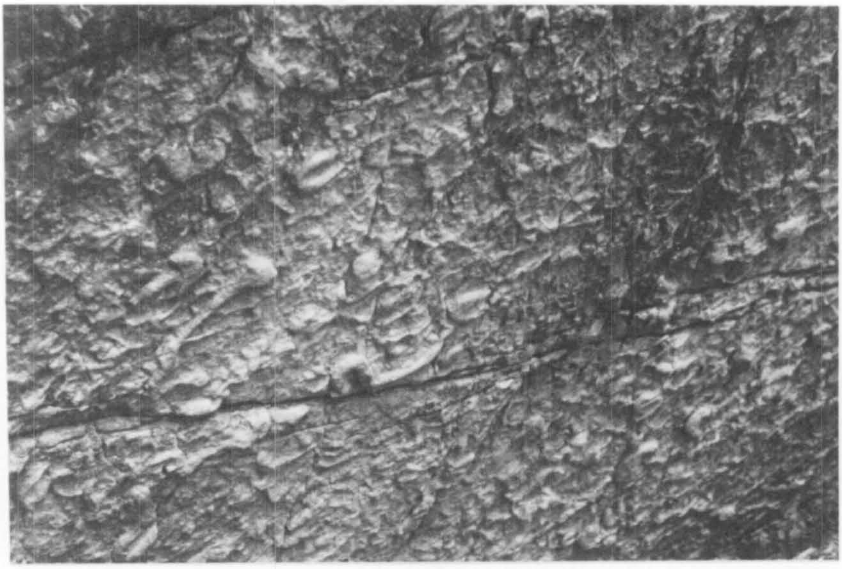
Figure 5.1.3: Oblique view looking up at basal surface of Weka Pass Stone. Mead Stream (S35/075452). Note density of *Thallasinoides* hypichnia. Scale = 20cm. *Photo: M. Lawrence.*

Figure 5.1.4: Polished slab of Phosphatic Conglomerate Bed from Clinton Stream (S49/018076). Angular, phosphatized calcilutite clasts floating in a matrix of glauconitic foraminiferal calcarenite packstone. B=cetacean bone fragment. T=lithified *Thallasinoides* burrow wall. Note variation in degree of phosphatization between clasts i.e. 1=slightly altered; 2=moderately altered; 3=intensely altered.

Figure 5.1.5: Plan view of Phosphatic Conglomerate Bed. Haumuri Bluff (S56/813732). Note cetacean bone (1); phosphatized brachiopod (2); and unphosphatized bivalve (3); as well as pebble size phosphatized lithoclasts. Chisel = 20cm. *Photo: M. Lawrence.*

Figure 5.1.6: Thin section photomicrograph (uncrossed polarizers) of part of phophatized micritic limestone lithoclast. Note c.1mm diameter boring with calcarenite (Weka Pass Stone) matrix infilling. Scale = 1mm.

JM 1/7 12212 Kaikoura Pensla S49 966886



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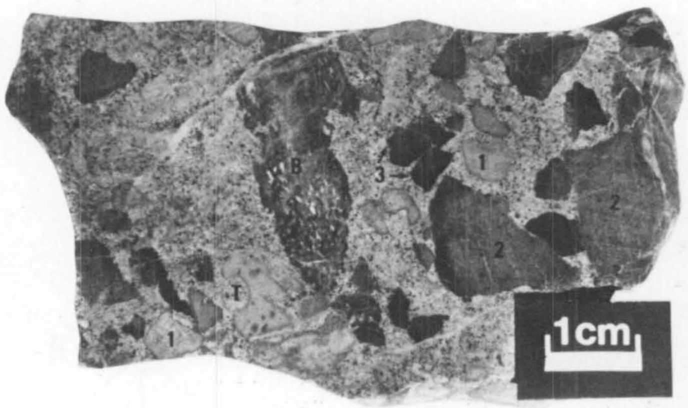

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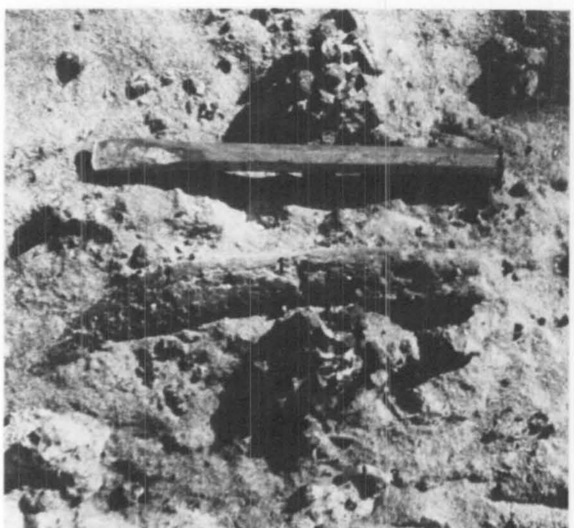

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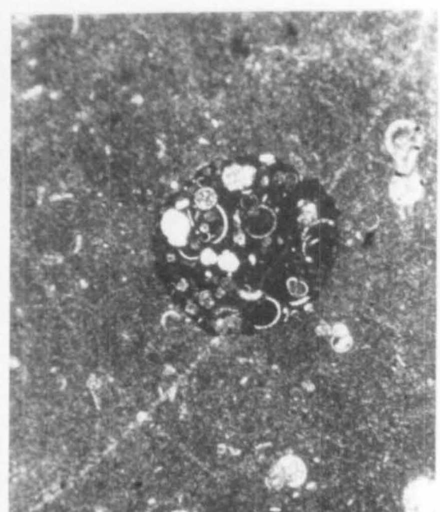

5.1.6

indurated, burrows extend down to a maximum depth of only c.10cm, but at Oaro and Haumuri Bluff, *Thallasinoides* penetrate 5m or more downward. Burrow diameters range from a few mm up to 10cm, although 1cm is the most common size. The burrows are passively infilled with sediment from the PCB. Phosphatization of burrow walls within the Upper Marl was not observed. Borings into the phosphatized clasts are uncommon but were recognized in one thin section (Figure 5.1.6). Although the walls of the illustrated example do not truncate allochems, their smoothness and near perfect circularity indicates their construction within lithified sediment.

Age

The age of initial accumulation of the PCB is unknown. Age determinations for the horizon have been made on samples of the interstitial matrix which was deposited at the end of conglomerate formation. Throughout most of Marlborough, the age of the matrix is early Waitakian (Appendix I). However, at several locations between Limestone Hill and The Fell, the horizon is overlain conformably by late Whaingaroan age Cookson Volcanics and Weka Pass Stone (e.g. 030/f31, 031/f7, 031/f149, 031/f61, 031/f242) and underlain by a thin sandstone containing microfauna ranging in age from late Whaingaroan to Duntroonian (031/f210).

The youngest sediments underlying the unconformity are late Runangan (032/f31, P30/f284).

Facies Interpretation

Paleoenvironmental analysis of the microfaunal assemblage in the sediments immediately beneath the unconformity, conglomeratic matrix, and the overlying sediments are indicative of accumulation in an oceanic environment at bathyal depths. Because of the absence of significant local discordance or features such as karsting, which have been demonstrated further south (e.g. van der Lingen et al. 1978; Lewis & Bellis 1984), it is unlikely that subaerial exposure ever occurred on the unconformity surface in Marlborough.

The marked angularity of clasts within the PCB suggests that they have undergone little, if any transportation. Furthermore, if lithoclasts were allochthonous in origin, it would be reasonable to expect local thick accumulation, rather than such a uniform distribution. The angularity and lack of plastic deformation, together with evidence of post-lithification boring activity, suggests that nodules accumulated as well indurated lithoclasts. On these grounds, the PCB is interpreted as the in situ residual lag derived from the breakup of an extensive phosphatized hardground formed on the post-erosional unconformity surface. The lack of preservation of an intact hardground in Marlborough can be attributed to the prolonged period of non-deposition following phosphatization. Mechanical weakening of the hardground, through progressive bioerosion eventually leads to subsequent breakup during high energy events (e.g. storms) or by vertebrate activity (Cullen 1982).

It has been suggested that hardgrounds result from early sea floor lithification during significant periods of non-deposition (Shinn 1969; Purser 1969). Precipitation of phosphate in the marine environment may occur by the replacement of allochems or micrite (Parker & Siesser 1972), and is promoted by the factors such as upwelling seasonal currents, low clastic supply, increased organic activity and winnowing bottom currents (Jarvis 1980).

Nodular phosphatic conglomerates very similar to the PCB have been described from Europe and the Mediterranean, in comparable lithologic sequences (Kennedy & Garrison 1975; Pedley & Bennett 1985). In these examples, hardground development is thought to be controlled as much by the increased permeability generated by infaunal activity, as by seawater geochemistry and oceanographic processes. A model similar to that proposed by Kennedy & Garrison (1975) accounts for all of the features displayed by the PCB (Figure 5.1.7).

Causes And Timing Of Unconformity Development

Differential erosion and local discordance across the unconformity surface probably reflects a period of contemporaneous tectonic activity. The timing of this tectonic pulse in Marlborough is constrained by the youngest underlying (late Runangan = 37.5 Ma), and the oldest overlying sediments (late Whaingaroan = 30Ma). However, because phosphate deposits require considerable periods of time (c.1m.y.) to form (D'Anglejan 1967), this uppermost limit is probably somewhat young. The younger age (early Waitakian = 28Ma) of matrix within the PCB throughout the rest of Marlborough probably reflects local subsidence which allowed sediment to accumulate several million years earlier near Seymour Stream.

The existence of this mid Oligocene tectonic event has previously been suggested by Spörli (1980) throughout New Zealand; Prebble (1980) in Marlborough; Lewis et al. (1979) in North Canterbury; van der Lingen

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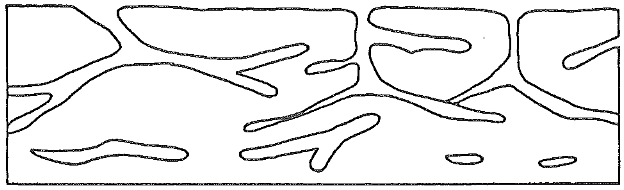

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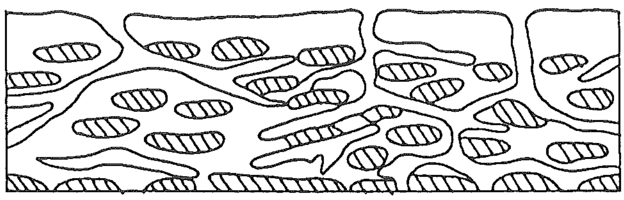

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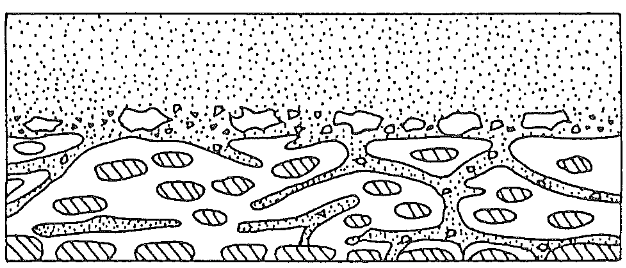


Figure 5.1.7: Flow diagram illustrating the proposed sequence of events leading to accumulation of the Phosphatic Conglomerate Bed (after Kennedy & Garrison 1975).

1. Pause in sedimentation leads to the development of an omission suite of *Thallasinoides* in a soft micritic substrate.

2. Early diagenesis associated with a longer pause in deposition leads to the growth of phosphatized nodules within firm sediment. Burrow systems are extended, the burrowing organisms avoiding hard nodules. Nodules eventually coalesce to form a lithified hardground.

3. Erosion by submarine currents of a structurally weakened hardground, produces a residual lag of reworked angular pebbles. Burrows are filled by, and lithoclasts embedded in a winnowed calcarenite.

et al. (1978) in Canterbury; and Lewis & Bellis (1984) in North Otago. A compressive phase (early Episode 2) of similar age, involving fold nappe development, has been recognized in Hawke's Bay by Pettinga (1982). In North Auckland, Ballance & Spörli (1979) recognize the obduction of an extensive allochthonous sheet of Upper Cretaceous to Upper Oligocene sediments (i.e. the Northland Allochthon) in Waitakian times.

Prebble's (1980) recognition of a late Oligocene (pre-Waitakian) tectonic event is based on his interpretation that disharmonic folding in the Middle Limestone is due to slump folding. However, this phase of deformation is interpreted here (see Chapter 4.5) to be synchronous with kink-folding resulting from Miocene or younger tectonics. Based on the occurrence of volcanics, Prebble (1980) also suggests limited Oligocene subduction in Marlborough. This suggestion is untenable because of his incorrect assumption that the Grass Seed Volcanics (Eocene) correlate with the Cookson Volcanics and are therefore Oligocene in age. In any case, Coote (1987) has shown that the Cookson Volcanics are of an intra-plate type and are unrelated to subduction.

Because there is no evidence of pre- or syn-unconformity faulting, and folds could only have been broad and gentle (judging from the minor discordance), tectonic activity is unlikely to have been intense in Marlborough. Sedimentary dikes cross-cutting the Upper Marl (see Chapter 4.6b), together with similar sandstone dikes described in north Canterbury (Lewis et al. 1979), may be synchronous with the tectonic event. An analogous relationship has already been demonstrated for dikes truncated by the sub-Teredo Limestone unconformity (see Chapter 4.2).

Submarine processes must be invoked to explain the differential erosion beneath the unconformity. Increased current activity is the most obvious explanation for marine erosion in what is interpreted as a bathyal setting. Kennett et al. (1972) propose initiation of a "Circum-Antarctic current" in Mid Oligocene times following separation of Australia from Antarctica (Molnar et al. 1975). Associated strong bottom currents flowing across the submerged New Zealand continental block, have been suggested by Carter & Landis (1982) as the primary cause for development of the unconformity in eastern New Zealand. Although there is no direct evidence for strong current activity on the surface in Marlborough, the rare lithic granules may have been derived from prolonged winnowing of the Upper Marl, in which these sporadically occur.

A major eustatic sea level fall (Vail et al. 1977; Loutit & Kennett 1981) at c.30Ma (Figure 7.11) is approximately synchronous with unconformity development. Although regression may be significant in terms of karst development on the unconformity, well to the south of the study area, its effect is unlikely to have been as dramatic in the bathyal settings suggested for Marlborough.

Neither of these alternatives can successfully explain the associated tectonic pulse. It is possible that the contemporaneous tectonism was independent of, and superimposed on, oceanographic processes. The recognition of this tectonic event on a wider scale raises the possibility of a third alternative: that regional tectonism was a significant contributing cause for mid Oligocene unconformity development throughout New Zealand. This proposal has previously been made by Lewis & Bellis (1984) with respect to an intra-Waitakian unconformity (presumably separate from tectonism associated with a late Whaingaroan unconformity) in North Otago. It is proposed here that the tectonic event was confined to the mid - late Whaingaroan in Marlborough, but may have continued into Waitakian times in North Otago.

Carter & Landis (1982) attribute the early Oligocene angular unconformity in western New Zealand to extensive tectonism associated with initial propagation of the Australian - Pacific plate boundary through New Zealand (Walcott 1978). These authors apparently do not consider the Oligocene unconformities in Otago, Canterbury, and Marlborough to be angular and therefore do not recognize significant tectonism in those areas. Whereas extensional tectonics may have dominated western areas of New Zealand, the nature of deformation beneath mid Oligocene unconformities in eastern New Zealand is clearly compressive.

Pettinga (1982) has also related the mid Oligocene compressive phase in Hawke's Bay to initiation of the Australian - Pacific plate boundary in New Zealand. There is no good reason why a similar interpretation should not be adopted for the same event in Marlborough. Although subduction may have occurred at this plate boundary in northern New Zealand during the Oligocene (e.g. Ballance & Spörli 1979), there is no evidence that it occurred synchronously in Marlborough or further south. The southward-decreasing intensity of deformation associated with the mid Oligocene tectonic event may reflect lateral variations in the angle of plate convergence along the boundary, similar to those known today (Walcott 1978).

Summary

The proposed sequence of events leading up to and including development of the PCB in Marlborough can be summarized as follows. Deposition of the Amuri Limestone was discontinued sometime during early Oligocene (post Runangan) times and was followed by a period of submarine erosion which was synchronous with a mild tectonic episode. Active erosion ceased but non-deposition continued and an extensive hardground was developed across southern Marlborough. Localized breakup of this surface began in the late Whaingaroan and sedimentation had resumed throughout Marlborough by early Waitakian times.

This interpretation depends largely on the correlation of the PCB beneath the Cookson Volcanics in the Limestone Hill - Seymour Stream area with the PCB throughout the rest of Marlborough. If this correlation is not valid, then the possibility that two separate unconformities are present must be considered. Such a situation can only be rationalized by the development of a late Whaingaroan unconformity in SW Marlborough which may or may not have extended into the rest of Marlborough. A separate early Waitakian unconformity followed which did not extend into the Limestone Hill - Seymour Stream area, but eroded the earlier unconformity (and any subsequently deposited sediments) elsewhere. This situation is considered unlikely because nowhere are the two unconformities preserved in the same section. In addition, phosphatized lithoclasts of Weka Pass Stone have not been discovered in the PCB of Waitakian age.

5.2 Cookson Volcanics (Group)

Name, Definition, And Synonomy

The name is derived from the Oligocene volcanics exposed near Mt. Cookson in Waiau, North Canterbury. Gregg (1964) first used the name Cookson Volcanics to describe "*basaltic pyroclastics and lava flows*" in that area. Coote (1987) has described the stratigraphy, petrography, and petrogenesis of the Cookson Volcanics in Waiau. Browne & Field (1985) have subsequently given the unit Group status. The synonomy of the unit in Marlborough is discussed in Reay (1980).

Distribution, Thickness, And Relation To Underlying Rocks

The Cookson Volcanics in Marlborough are restricted to an area between Grass Seed Stream and The Fell (see Reay 1980). The unit is thickest (38m) at Limestone Hill and thins to the north and south. The unit either disconformably overlie Amuri Limestone (Grass Seed Volcanics at Grass Seed Stream; Upper Marl at Seymour Stream), or is separated from the disconformity by the Phosphatic Conglomerate Bed (e.g. Appendix IV: JM 123).

Lithology

The dominant lithology is massive to poorly bedded, reddish brown to brownish grey, poorly indurated, calcareous, fossiliferous, fine sandy, basaltic tuff. At Limestone Hill (Appendix IV: JM 128), several thin (1-2m), vesicular basalt flows are intercalated in the lower 10m. In the same section, several thick (5-8m) marls, as well as thin (0.6-2m) limestones are present. The marls are similar to the uppermost Amuri Limestone (Upper Marl), and may be infaulted. The limestone is a massive to laminated and graded, light grey, well indurated, well sorted, calcarenite, packstone: slightly glauconitic, algal, bryozoan, foraminiferal, poorly washed biosparite.

Paleontology And Age

Macrofossils, which are moderately common in the tuffaceous lithologies, include small (<1cm) pectins, gastropods, fish teeth and bones. Foraminifera from intercalated non-volcanic lithologies show that the Cookson Volcanics in Marlborough are late Whaingaroan in age (O31/f61, f210).

Facies Interpretation

Paleoenvironmental interpretations of the microfauna (Appendix I) within the conformably underlying Phosphatic Conglomerate Bed indicate bathyal water depths. However, the presence of coralline algae within intercalated limestones suggests accumulation within the photic zone. However, sedimentary structures within these algal limestones indicate that they were redeposited. The thick marls (if not infaulted) may have accumulated during periods of volcanic quiescence. The presence of lava flows demonstrates that the eruptive source was relatively close. It is likely that the Cookson Volcanics between Limestone Hill and The Fell represent the distal deposits of a partly emergent submarine volcano and that the intercalated calcarenites were derived from its upper slopes.

5.3 Weka Pass Stone (Formation)

Name And Definition

The name Weka Pass Stone was first used by Hector (1877). Andrews (1963) gave the unit formal lithostratigraphic status as a Member within his Omihi Formation in North Canterbury. He defined the Member as "*the hard, cream-coloured, sandy limestone with disseminated fine glauconite, resting on the bored surface of the Amberley Limestone*". The Omihi Formation was included within the Motunau Group by Browne & Field (1985). It is proposed that in Marlborough, the Weka Pass Stone become a separate Formation within the Motunau Group.

Synonomy

Hector (1874):	"Fucoidal limestone"
Morgan (1916):	"Grey Marls"
Hall (1964):	"Whales Back Limestone"
Prebble (1976):	"Whales Back Limestone"
Osborne (1981):	"Top Limestone"
Browne & Field (1985):	"Spy Glass Formation"
Fergusson (1985):	"Whales Back Limestone"

Distribution And Thickness

The Weka Pass Stone extends throughout the study area as far north as Box Stream (c.8km NE of Coverham). At Cribb Creek (Appendix IV: JM 7) and Oaro (Appendix IV: JM 3), the Formation is absent and its stratigraphic position is occupied by the Waima Siltstone. The Formation reaches its maximum thickness (90m) between Seymour Stream and The Fell (Reay 1980). The minimum recorded thickness (6m) occurs at Haumuri Bluff (Appendix IV: JM 15).

Relation To Underlying Rocks

In the area between Limestone Hill and Wallow Creek, the Weka Pass Stone conformably overlies Cookson Volcanics tuffs. The contact is gradational over several metres in which thin interbedded tuffs persist up into the Weka Pass Stone (Reay 1980).

NE of Limestone Hill and Puhi Puhi River, the Formation unconformably rests on the Amuri Limestone Group (Figure 5.3.2). The contact in these areas is usually concordant in outcrop, although regional discordance can be demonstrated (Figures A2, B2, 2.1.2). *Thallasinoides* burrows commonly extend 10cm into the uppermost Amuri Limestone.

Elsewhere, the Weka Pass Stone is separated from the unconformity overlying the Amuri Limestone by the Phosphatic Conglomerate Bed. In these cases, sediment from the Weka Pass Stone forms the conglomeratic matrix and often penetrates into the Amuri Limestone as *Thallasinoides* burrow fill.

Reference Section

Kaikoura

The Weka Pass Stone is 56m thick and extends from the Phosphatic Conglomerate Bed (Figures 5.1.2 & 5.3.1) at S49/968885 up to the conformable contact with the Waima Siltstone at S49/967885 (Appendix IV: JM 1). This section was described variously by Browne & Field (1985) as (p.32) "*35m of* (unnamed) *Duntroonian sandy limestone*" and (p.41-42) "*c.10m* of *Waitakian to Otaian* age *Spy Glass Formation*".

Lithology

The Weka Pass Stone in Marlborough consists of cm-dcm thick limestones interbedded with mm-cm thick calcareous siltstones, greensands, or tuff. The limestone is a light greenish grey, very well indurated, very well sorted, calcarenite, packstone: glauconitic, packed foraminiferal biomicrite (Figure 5.3.3).

The detrital fraction (usually <1-2%) consists of very fine sand size, angular quartz grains, but locally contains abundant fragments of tuff. Angular coarse sand to granule size, phosphatized lithoclasts are common near the base of the Formation. Planktonic foraminifera are the dominant (>95%) allochems, although minor quantities of benthic foraminifera, sponge spicules, echinoid fragments are sporadically distributed. Coralline algae and bryozoan fragments are present within lenses of Weka Pass Stone at the top of the Cookson Volcanics. Well rounded glauconite grains, which often mimic the morphology of the associated foraminifera, are ubiquitous in amounts ranging from 1-5%.

The matrix is dominantly micrite, but contains minor quantities of smectite, illite, and kaolinite (Appendix II). Diagenetic minerals include cristobalite and clinoptilolite. In rare cases, the micritic matrix has been partly replaced by sparry calcite, to form a poorly washed biosparite. The $CaCO_3$ content averages c.77% and locally reaches 92% (Appendix II). A single limestone bed containing chert nodules (10cm thick) occurs at the base of the Formation in the Kaikoura reference section.

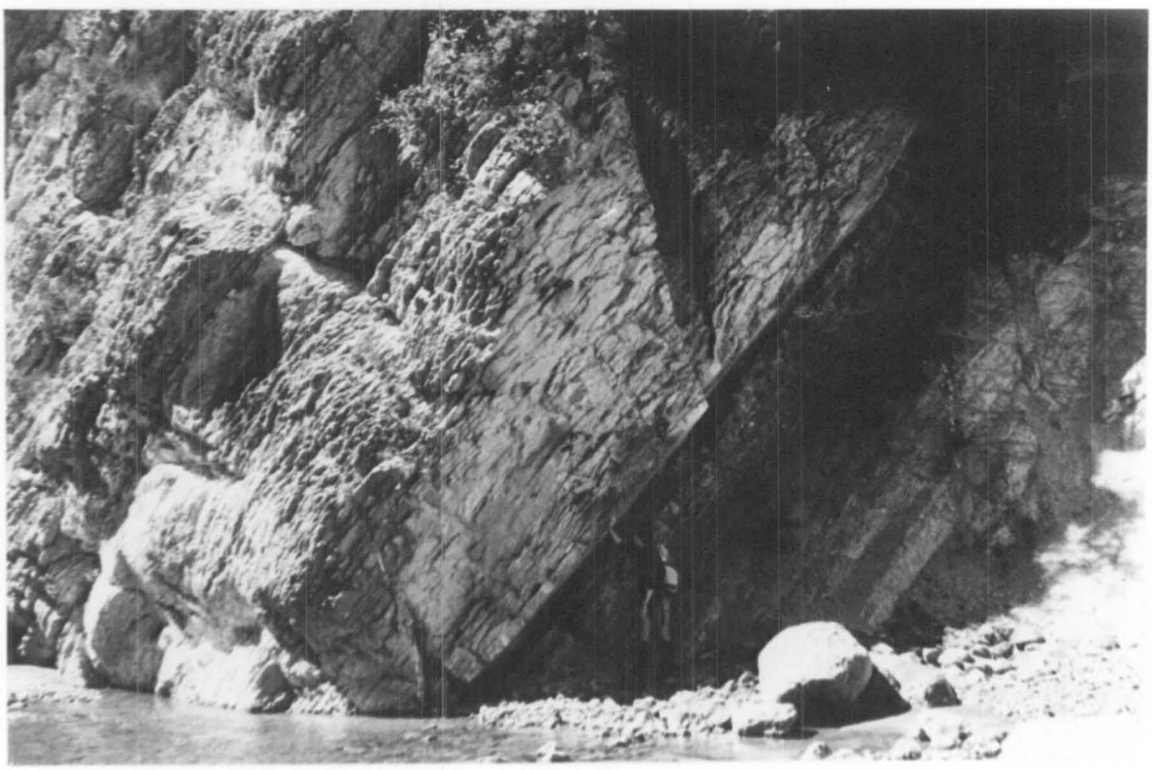
Figure 5.3.1: Basal 3-4m of Weka Pass Stone (base arrowed). Kaikoura (S49/968885). Hammer for scale.

Figure 5.3.2: Basal 6-8m of Weka Pass Stone. Mead Stream (S35/075452). Hand rests on base of Formation (see Figure 5.1.3 for view of basal surface). Note slight discordance in bedding across the unconformity.

Figure 5.3.3a,b: Thin section photomicrograph (uncrossed polarizers) of Weka Pass Stone. Note predominance of well sorted planktonic foraminifera. Scale = a:0.5mm; b:1.25mm.

JM 1/7 12212 Kaikoura Pensla S49 966886

5.3.1



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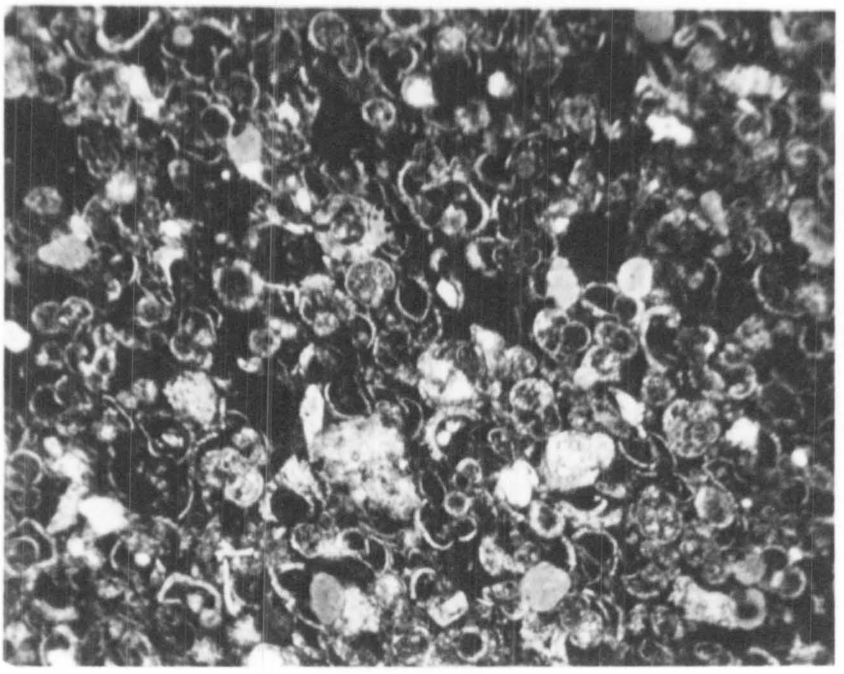
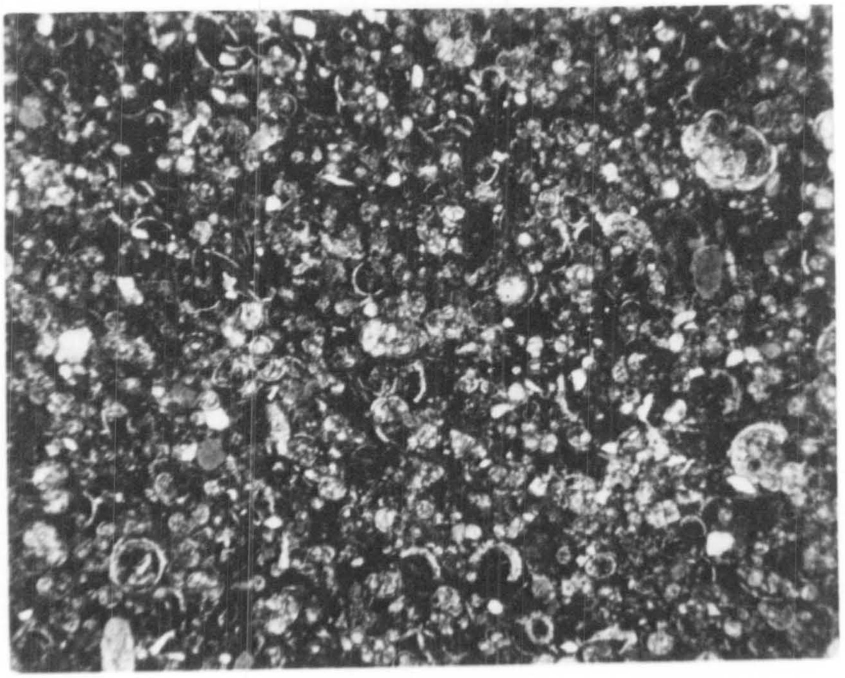


5.3.3a



5.3.3b

Greensands, which are typically interbedded with limestone in coastal outcrops, are 5-50mm thick and consist of uncemented glauconite (>50%) and detrital sand and mud. Apart from rare, poorly preserved foraminifera, these glauconitic intercalations are unfossiliferous. Interbedded thin, calcareous siltstones, which are more common in inland sections, are similar in lithology to the overlying Waima Siltstone.

Intact macrofossils are very rare in the Weka Pass Stone in Marlborough. Reay (1980) reported terabratulid brachiopods, pectins, and fish teeth, as well as concentrated horizons of shell hash in the Seymour Stream area.

Ichnology

Thallasinoides burrows, preserved in hyporelief on the base (Figure 5.1.3), and *Zoophycos* in the uppermost part of the Formation, were the only recognized ichnotaxa.

Age

In the Seymour Stream - Limestone Hill area, the Formation varies in age from latest Whaingaroan at the base to Waitakian near the top. Elsewhere in Marlborough, the Formation is entirely early Waitakian (Appendix I).

Facies Interpretation

Several previous authors (e.g. Hall 1964; Prebble 1976) have included the Weka Pass Stone within the Amuri Limestone. Significant lithologic differences, together with the intervening major unconformity, make this inclusion untenable.

From microfaunal assemblages (see Appendix II), the Formation was apparently deposited at similar water depths (i.e. outer shelf to bathyal) to the underlying Amuri Limestone. Qualitatively, the major components (i.e. foraminifera, micrite, glauconite) in the Weka Pass Stone are the same as those in the Amuri Limestone. Planktonic foraminifera, which seldom exceed more than 5-10% of the latter, form a much larger proportion (c.50% or more) of the former. Localized metre-scale cross-bedding has been provided as evidence for strong current activity during deposition of the Weka Pass Stone in South Canterbury (Carter & Landis 1982). However, direct sedimentological evidence for current activity in Marlborough has not been discovered and can only be inferred from the winnowed nature of the sediment.

Correlation

Most authors have correlated the Weka Pass Stone in Marlborough with that in North Canterbury. The two facies are very similar in age, lithology and stratigraphic position (Armstrong 1972). Although Browne & Field (1985, p41) separate the unit as a Formation (Spy Glass Formation), they regard it as lithological distinct from the Weka Pass Stone in North Canterbury. They argue that the two units were deposited in separate basins. The evidence they provide for this assumption is the presence of an intervening "*NW trending belt of non-deposition*" (Andrews 1963). However, because this area of "non-deposition" may also be interpreted as a region where the sequence was eroded, there is no good evidence that the two facies were not once continuous. In any case, Browne & Field (1985, Fig. 5) show an isolated sequence of Weka Pass Stone to the north of the area of "non-deposition".

Chapter Six

SANDSTONE PETROGRAPHY

Methods

125 samples from various sandy lithologies associated with the Amuri Limestone were examined petrographically. 41 representative thin sections were selected for detailed analysis, the remainder being rejected on the grounds of unsuitability for point-counting.

Most feldspar grains display at least some degree of alteration, enabling them to be readily distinguished visually from quartz. Confidence that this technique was adequate can be gained from several previous analyses (e.g. Reay 1980; Crampton 1985) of comparable lithologies which produced closely similar feldspar totals. Feldspar staining was initially attempted but abandoned because of the hazardous nature of the chemicals involved.

A minimum of 500 points were counted for each thin section to provide a modal composition. Samples with a higher proportion of cement, matrix, and/or non-detrital grains were analysed using more points to ensure that the minimum number of detrital (QFL) grains counted exceeded 400.

Grain size measurements were made visually using a microscope cross-hair scale and the mean and maximum values were recorded. Estimates of rounding and sorting were made visually from comparison charts provided in Lewis (1984). The compositional categories listed below were found to include in excess of 99.9% of the total rock in each case.

Qm : Monocrystalline quartz.
Qp : Polycrystalline quartz grains (excluding chert).
Fp : Monocrystalline plagioclase.
Fk : Monocrystalline K-feldspar.
L : Lithic fragments.
M : Mica.
Py : Pyrite.
Fbth : Benthic foraminifera.
Fplk : Planktic foraminifera.
Glc : Glauconite.
Mtx : Matrix.

Other : Fossil fragments, rip-up clasts, etc.
Cmt : Cement.

Colour was determined by comparison of fresh, dry hand specimen surfaces with the Geological Society Of America "Rock Colour Chart".

Terminology And Nomenclature

Sample descriptions provided in Appendix III are modified from layouts presented in Lewis (1984). Modifications to the final full descriptive name were necessary to allow for mixed carbonate - siliciclastic samples (e.g. Teredo Limestone). Final compositional arenite nomenclature follows the Q:F:L system of Folk et al. (1970). Rocks composed of >50% non-carbonate components are classified as arenites. Those samples where the total primary carbonate fraction (i.e. mainly foraminifera and micrite) exceeds the total combined siliciclastic and authigenic component are termed limestones. Textural carbonate nomenclature follows the Dunham (1962) scheme, and the Folk (1959) classification is adopted for compositional descriptions. Although averaging more than 50% carbonate, the Teredo Limestone is discussed in this section because of its high siliciclastic component and close similarity to the Claverley Sandstone.

Monocrystalline quartz was broadly divided into grains with either undulose or non-undulose (straight) extinction. Undulose extinction is arbitrarily taken here to mean extinction through a microscope stage rotation of >5°.

6.1 Claverley Sandstone

Description

The Claverley Sandstone, throughout the study area, is uniformly a very fine to fine sandy subfeldsarenite (Figure 6.1.1). The modal grain size is generally close to the very fine sand to fine sand boundary (0.125mm; 3ø units). The coarsest grains measured during thin section examination range up to medium sand grade (0.3mm), and constitute much less than 1% of the sediment.

The sand fraction is either well sorted or very well sorted and always forms a distinct mode separated from the clay size matrix. Samples can be divided between those in which matrix forms either c.10% (i.e. grain supportive) or c.50% (i.e. matrix supportive) of the total sediment. Matrix supportive samples are classed as either muddy sandstones (matrix <50%) or sandy mudstones (matrix >50%).

Rounding of most detrital grains ranges from angular to very angular; chert lithic fragments are more rounded than other grains.

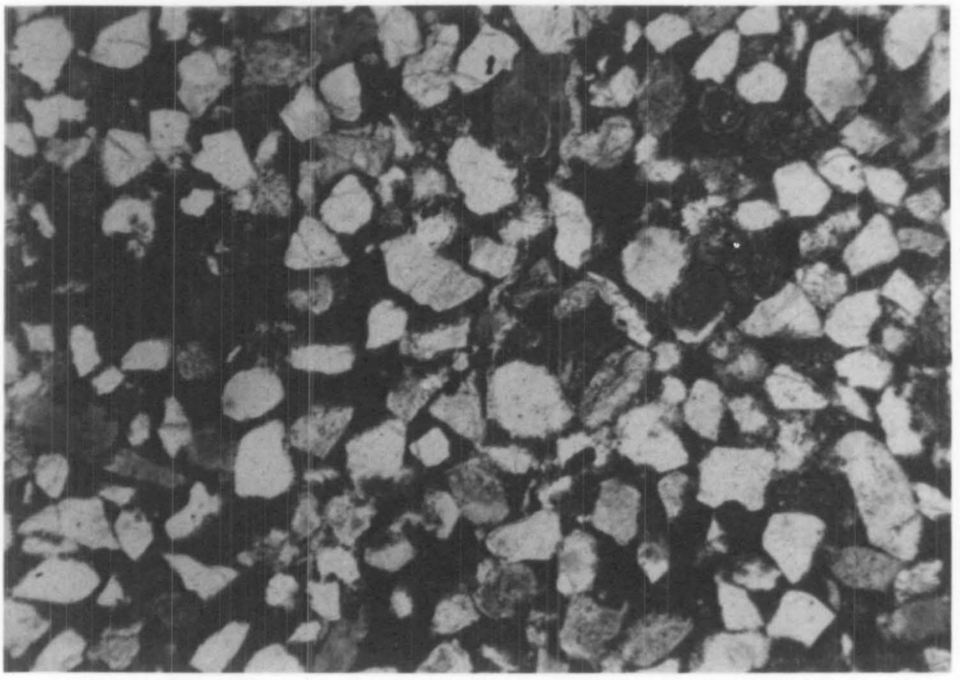
A summary of the modal composition of the Claverley Sandstone from thin section data is presented in Table 6.1.1. Individual descriptive analyses are included in Appendix III.

Detrital monocrystalline quartz predominates over polycrystalline varieties (Qm/Qp=3.5). Both strained and unstrained Qm is present in most cases. Finely sutured and coarsely equant Qp grains are also approximately evenly represented although stretched crystals are rare. Fresh, clean Qm, as well as grains containing inclusion trails, are equally common. Worn overgrowths on quartz grains were not observed in any of the samples.

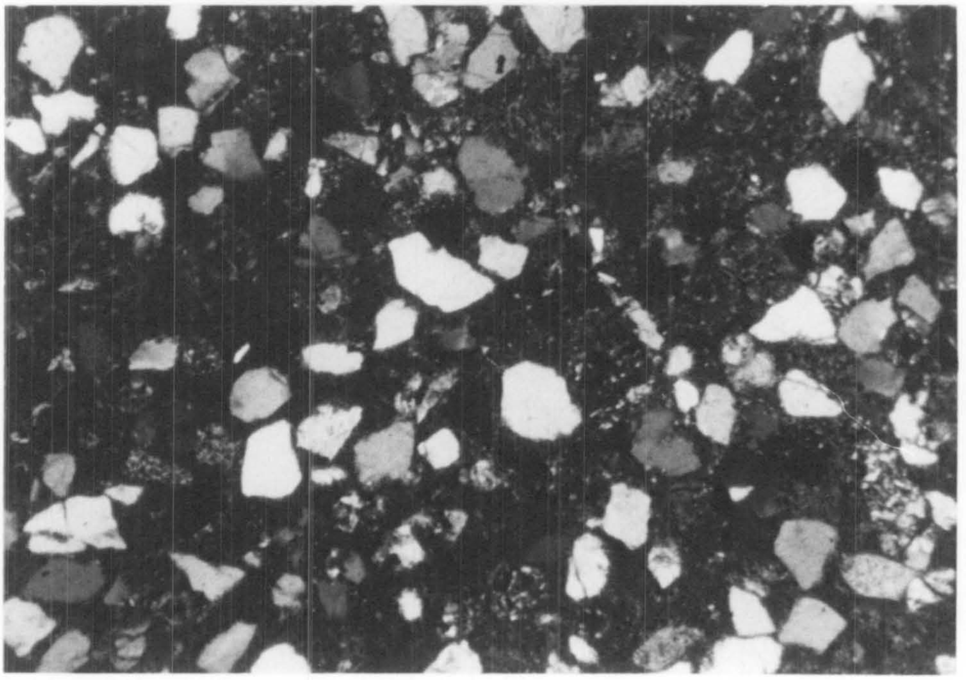
Feldspars, with the exception of rare microcline, all display some degree of albitization. K-feldspar, which is dominantly orthoclase, tends to be more altered than plagioclase. Almost invariably, twinned plagioclase grains have an albite composition. Alkali feldspar tends to be slightly more abundant than plagioclase (Fk/Fp=1.3).

Lithic grains form only a minor fraction of the total composition (mean: 2.2%) and consist of aphanitic volcanics (basalt?) and chert with minor amounts of indurated siltstone. Volcanic fragments display a rel-

Figure 6.1.1a,b: Thin section photomicrograph (a=uncrossed polarizers; b=crossed polarizers) of Claverley Sandstone (see Appendix III: JM 18/6) for description). Note well sorted, angular detrital sand fraction. Scale = 0.5mm.



6.1.1a



6.1.1b

atively low degree of alteration. Siltstone and chert grains are commonly quartz-veined. A single grain of fresh myrmekite was observed in one sample (Appendix III: JM 25/8). Very rare schistose?fragments were observed in two widely separated samples (Appendix III: JM 10/3, JM 4/1).

Table 6.1.1. Modal composition data for Claverley Sandstone, Teredo Limestone and Fells Greensand.

	Claverley Sst			Teredo Limestone			Fells Greensand		
		Mean			Mean			Mean	
Qm		38.5			22.4			44.0	
Qp		10.9			4.3			6.1	
Fp		2.7			2.0			1.0	
Fk		3.6			1.4			2.0	
L		2.2			2.0			.4	
M		.7							
Py		.3			.3			.2	
Fbth		.3			.3				
Fplk		.8			7.0			.1	
Glc		2.9			9.2			6.0	
Mtx		30.0			50.0				
Other		.3			1.1				
Cmt		6.7						40.1	
	-1sd		+1sd	-1sd		+1sd	-1sd		+1sd
Q*	82.9	86.2	89.5	78.2	82.0	85.8	91.5	94.0	96.5
F*	7.3	10.1	12.9	8.6	11.4	14.3	2.9	5.2	7.5
L*	1.6	3.7	5.8	3.6	6.6	9.6	.1	.8	1.4
Qm*		66.5			69.8			82.2	
F*		10.9			10.6			5.6	
Lt*		22.6			19.6			12.2	

Q* : Total quartz grains including monocrystalline Qm and polycrystalline Qp varieties (excluding chert).
F* : Total monocrystalline feldspar including plagioclase and K-feldspar Fk.
L* : Total polycrystalline lithic fragments.

Qm* : Total monocrystalline quartz.
F* : Total monocrystalline feldspar.
Lt* : Total polycrystalline lithic fragments including Qp.

Mica, which is nearly all muscovite, is a ubiquitous component although it only rarely comprises >1% of the total composition.

Although generally present in minor quantities (<0.5%), pyrite is a common constituent and is locally concentrated (c.30%) in sequences where the Claverley Sandstone is condensed or anomalously thin.

Biogenic constituents, excluding micrite, are rare (c.1%). Microfossils include mostly unbroken foraminiferal tests and large sponge spicules. Planktic foraminifera dominate over benthics by a ratio of approximately 3:1. Chalcedonic spicules with an average diameter of 0.15mm often have a thin central canal infilled with glauconite. Very rare macrofossil debris consists mainly of comminuted echinodermal and indeterminate molluscan fragments, as well as broken teeth.

The most abundant non-detrital grain type is glauconite. Although this mineral is only present in concentrations averaging 2.9%, it locally exceeds 10% and is ubiquitous within the Claverley Sandstone. Intact grains are generally larger than the modal detrital grain size in the surrounding sediment. External morphology is dominantly rounded-lobate while internal textures are principally random microcrystalline. Oriented or patch-oriented microcrystalline grains (McConchie & Lewis 1980) are locally conspicuous.

Rare, outsized, very angular, phosphatized grains were observed in several thin sections and appear to coincide with relatively high glauconite concentrations. Since these grains may be authigenic or intrabasinally-derived (perigenic), they were not included as lithic fragments. More obvious but equally rare are the larger pebble size clasts that occasionally form discontinuous horizons. The parent material for these nodules is both lithic and bioclastic. Phosphatized fossils include bored bivalves and corals. Lithic clasts have a hard, glossy patina coating which is usually only a few mm thick and a core that is relatively unaltered. Algal boring of sand-size phosphatic grains was observed in samples from Kaikoura Peninsula.

The granule-pebble population of the Claverley Sandstone is composed of a mixture of very well indurated sandstone/mudstone (40%), vein quartz (10%) and moderately indurated (both phosphatized and unphosphatized) sandstone (50%).

The composition of the matrix is variable and ranges from non-carbonate mud to relatively pure micrite. XRD analysis (Appendix III) shows that the clay mineralogy of the acid insoluble residues consists of a mixture of illite, smectite and kaolinite. In several samples, calcite cement either partially or wholly replaces the interstitial matrix.

Petrographic examinations were made on six miscellaneous sandstones which are approximately coeval with, or slightly older than the Claverley. These samples include intercalated sandstones and (*)clastic dikes from the Woolshed Formation (JM 300/8, JM 10/4, JM 704/1, *JM 40/12) and anomalous sandstones within the Mead Hill Formation (SS1, JM 300/6). All samples have a texture and composition which is very similar to that of the Claverley Sandstone. Minor exceptions include a much higher ratio of monocrystalline to polycrystalline quartz (Qm/Qp >10) and a total absence of biogenic material (except in those samples interbedded with Mead Hill Formation). The lithologies most similar to the Claverley in terms of Q:F:L composition and texture are the interbedded sandstone (JM 10/4) and clastic dike (JM 40/12) from the southern facies of the Woolshed Formation.

Interpretation

Texture

The combination of well sorted sand with a high degree of angularity indicates a "mature" sediment in terms of Folk's (1951) textural maturity scale. However, the presence of more than 5% detrital clay indicates that a textural inversion has occurred during or since deposition.

Several possible causes for this textural inversion are:

1) Reworking of older "mature" sediments by relatively low energy processes allowing detrital clay to accumulate. The nature of the erosional unconformity at the base of the Claverley Sandstone suggests that winnowing of the underlying Woolshed Formation probably occurred (see Chapter 3.2). The close textural (and compositional) similarity between the Claverley Sandstone and sandstones in the Woolshed Formation supports this alternative.

2) Biogenic homogenization of clean, mature sandstones and interbedded mudstones. This possibility can be discounted because in those areas where bedding is preserved (e.g. Figures 3.2.2 & 3.2.7), interbedded mudstones are not present.

Composition

The Q:F:L composition of the detrital sand fraction of the Claverley Sandstone is shown in Figure 6.1.2 and listed in Table 6.1.1. Most points cluster within a narrow compositional range in the subfeldsarenite field of Folk et al. (1970) indicating a relatively mature sediment.

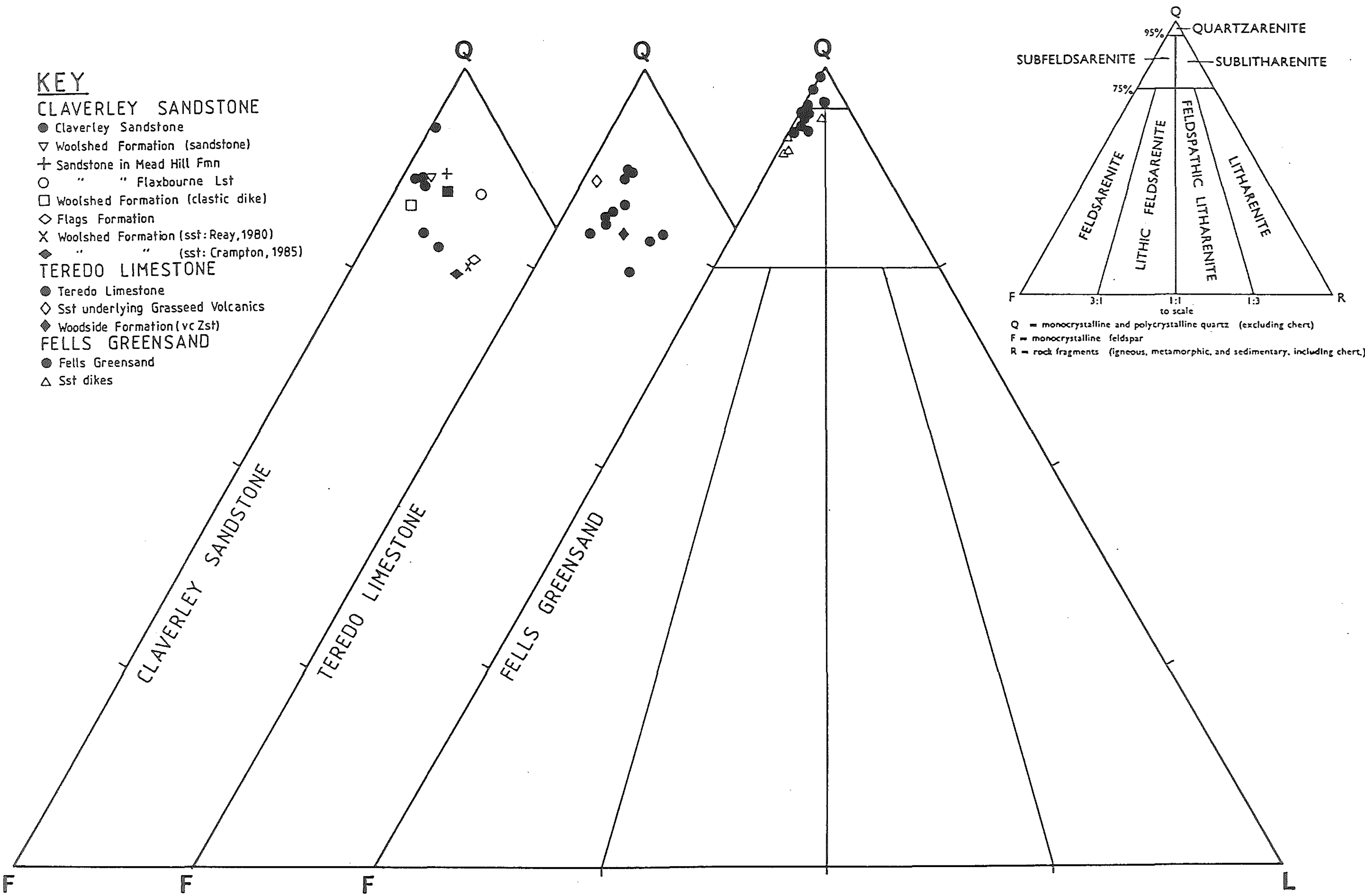


Figure 6.1.2: Q:F:L data for Claverley Sandstone, Teredo Limestone, Fells Greensand and related lithologies. Arenite classification after Folk et al. (1980).

The high degree of mineralogical maturity may be partly a function of the relatively fine grain size of the samples. A possible bias toward monocrystalline quartz, feldspar and fine grained lithics (e.g. chert, basalt, siltstone), at the expense of polycrystalline quartz and coarser lithics (e.g. sandstone, granite) may be reflected in the results.

Provenance

Field and textural relations suggest that the Woolshed Formation was a major direct supplier of sediment to the Claverley Sandstone (see Chapter 3). The first standard deviation field of Q:F:L data for the Claverley Sandstone (Figure 6.1.3) straddles the boundary between the "continental block" and "recycled orogen" provenance fields of Dickinson & Suczek (1979). A secondary discriminatory Qm:F:Lt plot, which helps to balance the effect of fine grain size, shows that the Claverley Sandstone falls well within the range of the recycled orogen field and most closely to either a collision or foreland uplift orogen. From the nature of the Rangitata Orogeny (e.g. Bradshaw et al. 1980), this type of provenance field might be expected from a Torlesse Supergroup-dominated source area.

The presence of chert and minor schistose lithic fragments is not incompatible with such an interpretation. While it is evident that much of the detrital fraction is ultimately Torlesse-derived, it is likely that the basalt fragments, because of their consistently fresh appearance, were derived from the younger mid Cretaceous (Ngaterian) age Gridiron Formation volcanics or their equivalents. If these volcanics were being eroded, then it is probable that the associated sediments were also available as source rocks. Minor quantities of fresh detrital microcline and myrmekite may suggest the presence of at least some granitoids in the source area, although both of these grain types have been recorded from Torlesse sediments (MacKinnon 1980).

Ultimate derivation from the Torlesse Supergroup, which is an extremely immature sediment (MacKinnon 1983), must be reconciled with high level of compositional and textural maturity in the Claverley Sandstone. This problem can be resolved if the Formation was mainly derived (via the Woolshed Formation) from post-Torlesse sediments (e.g. Split Rock Formation, Gridiron Formation) which were themselves recycled from Torlesse (e.g. Figure 6.1.3). A multi-step recycling mechanism for the Claverley Sandstone is shown in Figure 6.1.4.

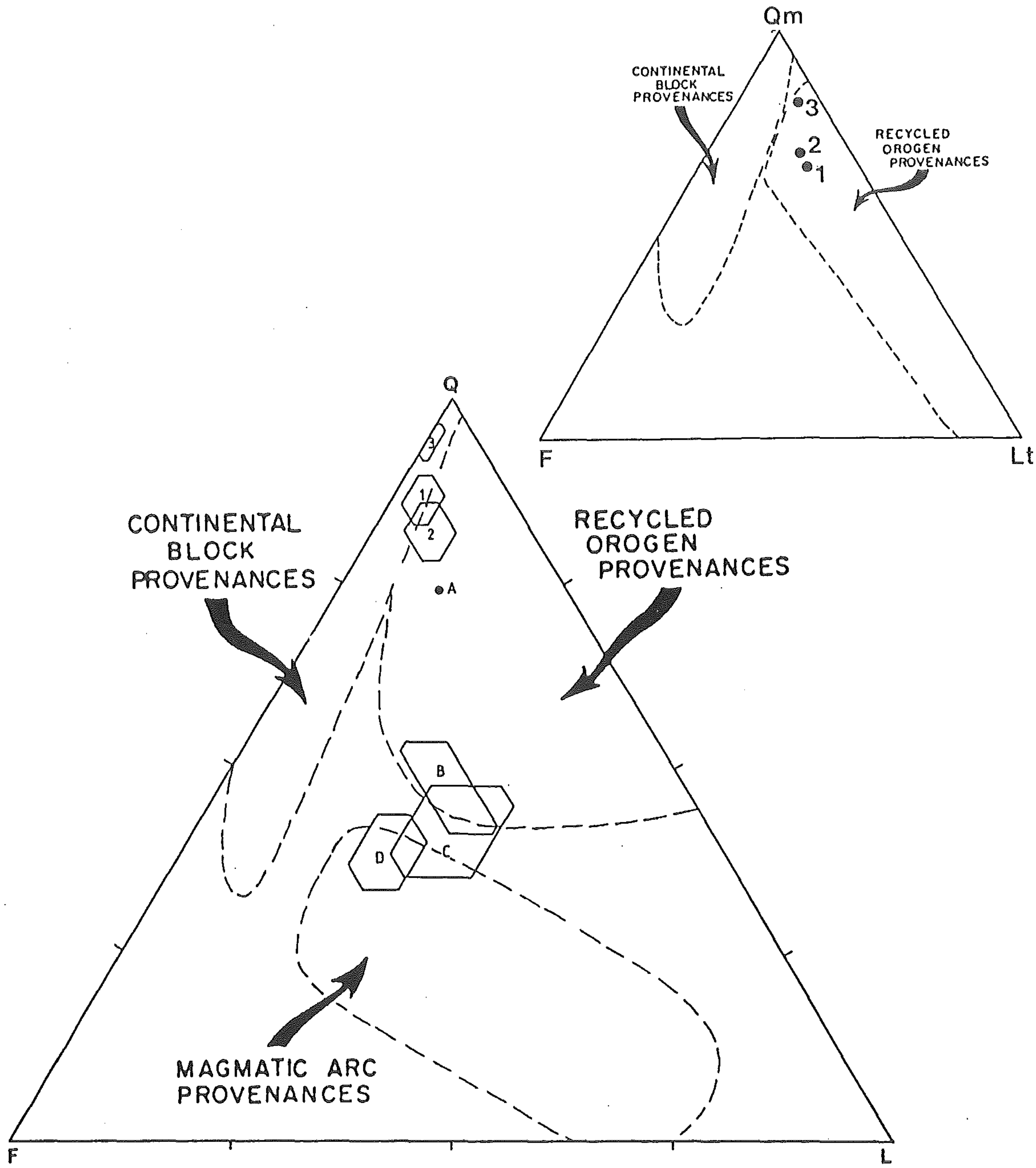


Figure 6.1.3: Comparison of Q:F:L first standard deviation fields of Claverley Sandstone, Teredo Limestone, Fells Greensand with older sandstones in Marlborough, versus provenance fields of Dickinson & Suczek (1979). Qm:F:Lt plot of mean values allows additional discrimination.

1. Claverley Sandstone (Haumurian) } This study
2. Teredo Limestone (Waipawan) } This study
3. Fells Greensand (Bortonian) } This study

A. Woolshed Formation (mean sandstone) } Crampton (1985)
B. Bluff Sandstone (Arowhanan) } Crampton (1985)
C. Split Rock Formation (Motuan) } Reay (1980); Ritchie (1986)
D. Torlesse (Early Cretaceous) } Crampton (1985)

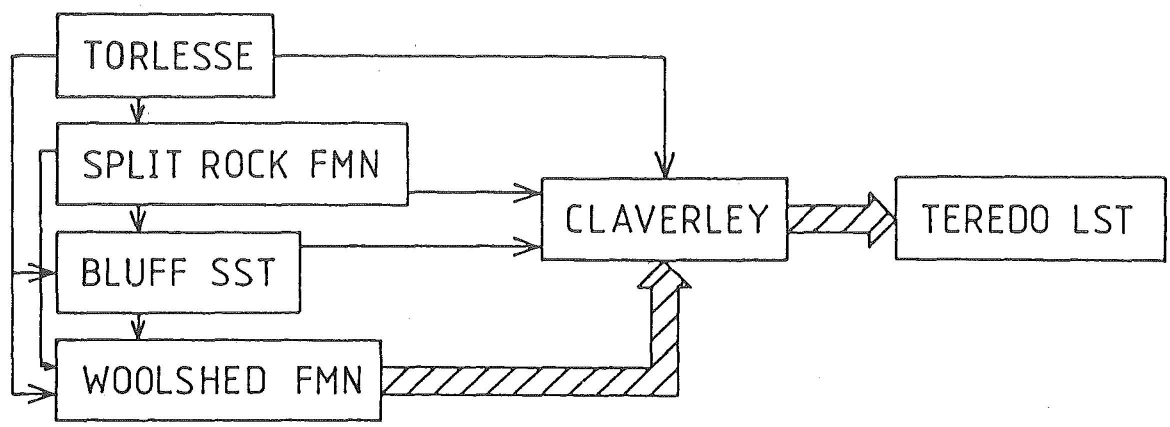


Figure 6.1.4: Schematic inferred provenance relations for the siliciclastic fraction of the Claverley Sandstone and Teredo Limestone. Width of arrows indicates relative volumetric importance of each source.

6.2 Teredo Limestone

Description

The Teredo Limestone is often characterized by a polymodal grain size distribution. Individual modes are well sorted and compositionally distinct. The dominant modes are:

1) detrital sand (mean: 0.10mm [3.3ø units]
   or 0.20mm [2.3ø units])
2) glauconite (mean: 0.20mm [2.3ø units])
3) foraminifera (mean: 0.15mm [2.7ø units])

Relative percentages of each mode are highly variable (Figure 6.2.2). Occasional medium to coarse sand grains (0.50mm maximum) are present in the detrital fraction. Glauconite always has a modal grain size approximately 0.5ø units greater than the associated detrital sand fraction.

Each of the sand modes has its own distinct class of rounding: detrital sand grains range from angular to very angular; unbroken foraminifera are well rounded; glauconite is commonly sub rounded.

The overall textural characteristics of the detrital sand fraction of the Teredo Limestone compare very closely with those of the Claverley Sandstone (compare Figure 6.2.1 with Figure 6.1.1).

The mean composition of the Teredo Limestone is given in Table 6.1.1. The siliciclastic detrital component comprises 32% of the sediment. Monocrystalline predominates over polycrystalline varieties of quartz (Qm/Qp=5.2). Qm grains are nearly all unstrained, with a small percentage containing inclusion trails. Both sutured and unsutured Qm grains are present in nearly all samples, although finely sutured grains are usually less abundant. Stretched polycrystalline quartz and worn overgrowths were not observed in any of the samples examined.

The overall degree of feldspar alteration is approximately the same as that in the Claverley Sandstone. Plagioclase, almost exclusively of albite composition, is usually more abundant than potassium feldspar (Fk/Fp=0.7). K-feldspar is largely orthoclase, although a small but significant amount of fresh microcline is often present. Perthitic textures were recognized in several samples.

Lithics constitute an average of only 2.0% of the modal composition. Although chert is the dominant lithic component, siltstone, moderately weathered basalt, and schist were all recognized in minor quantities. Quartz veins were observed in several medium to coarse sand-size siltstone grains.

Muscovite, which was the only mica recognized, was observed in only two samples in very minor quantities.

The pyrite content ranges from much less than 0.1% to a maximum of 1.0%. Pyrite most commonly occurs as very fine grained framboids or chamber replacements within foraminiferal tests or glauconite.

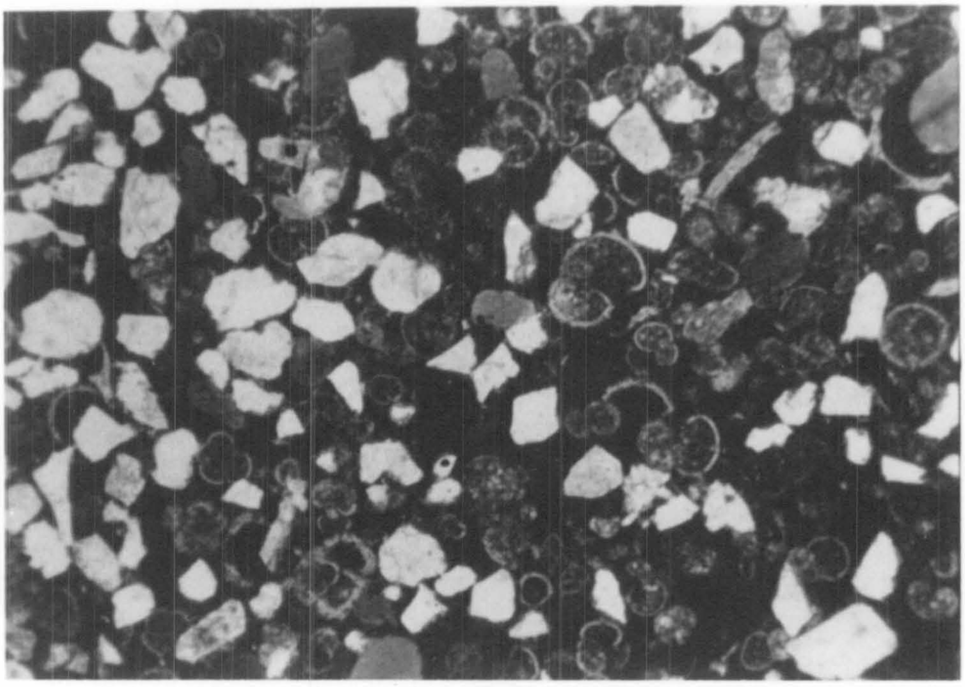
Glauconite is a ubiquitous and generally major component (mean: 9.2%) of the Teredo Limestone. A maximum value of 23.2% was recorded in thin section (Appendix III: JM 43/17) and at Wallow Creek (Appendix IV: JM 125), the Formation contains >50% glauconite. The external morphology of many grains closely resembles the internal chambered structure of planktonic foraminifera. The internal texture is dominantly randomly oriented microcrystalline. Intact tests still surround many grains and it is suggested that most of the remaining uncoated grains are internal casts from which tests have been abraded.

Small quantities (<3.0%) of angular phosphatized rock fragments up to very coarse sand size are present in most samples. Most of these grains appear to be replacing foraminiferal biomicrite. Probable algal borings were observed in one grain (Appendix III: JM 52/5).

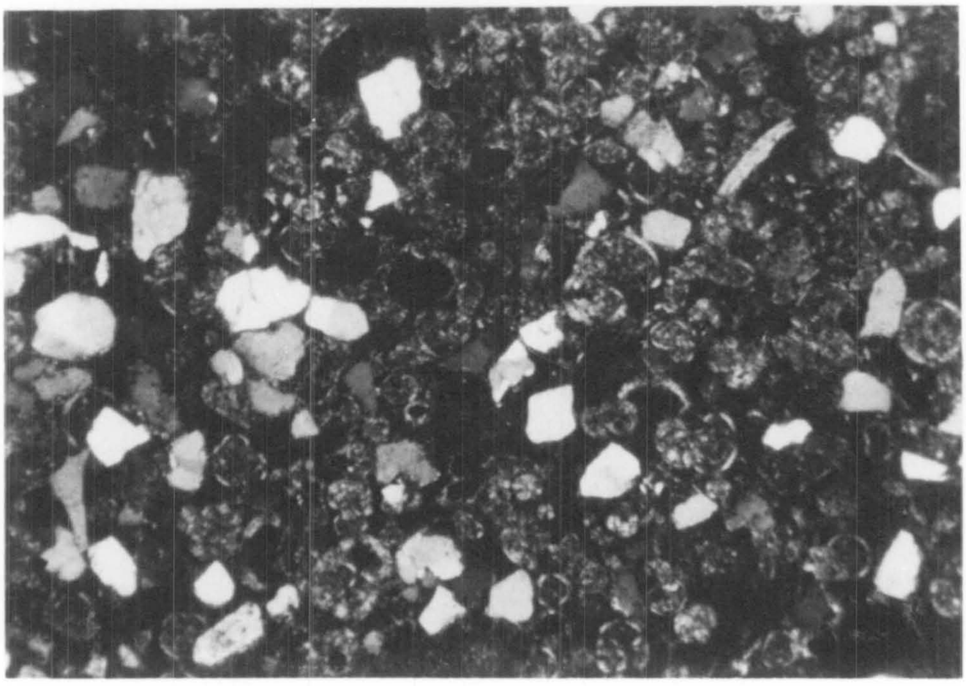
The dominant allochems are foraminifera (mean: 7.3%; max: 21.8%). Unbroken, delicate, thin-walled planktonics are more numerous than benthics (P:B=14). Sponge spicules of a size and type indentical to those in the Claverley Sandstone are common and locally comprise up to 4% (Appendix III: JM 2/9). Other sand sized biogenic material includes molluscan and echinodermal fragments and rare teeth.

The clay sized matrix is composed of a mixture of micrite and minor quantities of illite. Sparry calcite cement is often present within foraminiferal chambers. XRD analyses showed that both cristobalite and clinoptilolite are locally important constituents (Appendix III: JM 5/1), although neither mineral was detected in thin section.

Figure 6.2.1a,b: Thin section photomicrograph
(a=uncrossed polarizers; b=crossed polarizers)
of Teredo Limestone (see Appendix III: JM 128/1
for description). Note high percentage of planktonic foraminifera and similarity in texture of
detrital sand fraction to that in Claverley
Sandstone (Figure 6.1.1). Scale = 0.5mm.



6.2.1a



6.2.1b

The 1m thick sandstone directly underlying the Grass Seed Volcanics in Bluff Stream (Appendix III: JM 50/24), is compositionally (detrital) and texturally very similar to both the Claverley Sandstone and Teredo Limestone. Minor differences include a very high ratio of monocrystalline to polycrystalline quartz (Qm/Qp>60). The ratio of K-feldspar to plagioclase (Fk/Fp=0.5) and the absence of basalt rock fragments would suggest that the rock is more akin to the Teredo Limestone. However, the paucity of foraminifera supports an affinity with the Claverley Sandstone.

The sample of interbedded sandstone from the Woodside Formation (Appendix III: JM 200/1), although closely resembling Teredo Limestone in terms of its Q:F:L composition, has some important differences. The relative abundance of monocrystalline quartz (Qm/Qp>60), the high mica content and lack of foraminifera, glauconite and micrite are all important distinguishing features.

Interpretation

Texture

The Teredo Limestone can best be described in terms of a 4 component system containing micrite, bioclasts (essentially all foraminifera), glauconite and siliciclasts (Figure 6.2.2). The detrital sand fraction of the Teredo Limestone represents a texturally "mature" sediment almost identical to that of the Claverley Sandstone. Most of the glauconite appears to have precipitated within the tests of planktonic foraminifera.

The textural complexity of the sediment indicates that a complicated set of depositional processes was in operation. It is unlikely that detritus, glauconite, and unreplaced foraminifera were transported (and sorted) together because of the lack of hydraulic equivalence between the three sand modes. Authigenic glauconite, although always larger (and heavier) than the associated detritals, probably precipitated after accumulation of the siliciclastic fraction. However, large foraminifera (in which the glauconite subsequently formed) may have accumulated in winnowing conditions simultaneously with the detrital sand. Smaller, unreplaced foraminifera (and later micrite) accumulated as current speed decreased and conditions became unfavourable for glauconitization. Infaunal bioturbation resulted in homogenization of all modes.

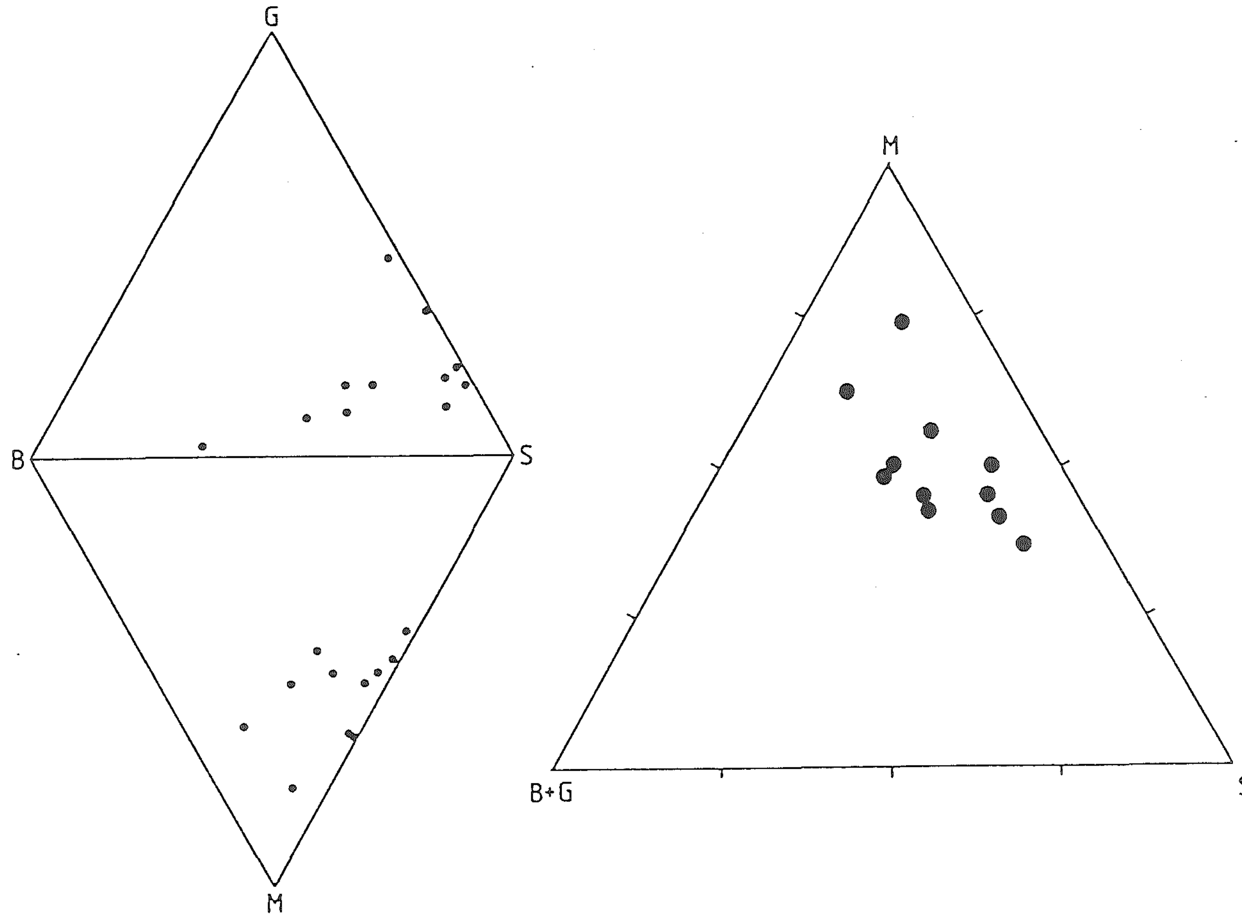


Figure 6.2.2: Ternary and quaternary plots of the main constituents of the Teredo Limestone. M=micrite; S=detrital sand; G=glauconite; B=bioclasts (mainly planktonic foraminifera).

Composition

The Q:F:L distribution (Figure 6.1.2) shows that there is also very little difference from the Claverley Sandstone in terms of the detrital composition. The detrital fraction of the Teredo Limestone appears as a slightly more mature than the Claverley Sandstone on a Qm:F:Lt plot (Figure 6.1.3). The higher Qm/Qp value for the Teredo also indicates a higher degree of mineralogical maturity. The apparent anomaly of a lower Fk/Fp ratio may be an artefact of the low total feldspar count not being statistically significant. The overall increase in the percentage of more stable lithics (i.e. chert) is also an indication of greater maturity.

Provenance

From field evidence (see Chapter 4.2), it can be shown that in many localities, the Claverley Sandstone supplied detritus during accumulation of the Teredo Limestone. Whether the dominant mechanism was direct erosion (e.g. Figure 4.2.10) or clastic dike extrusion (e.g. Figure 4.2.12) is unclear, although it is evident that both processes were active in supplying detrital sediment. Glauconite might also be expected to have been recycled from the Claverley Sandstone and not all of the glauconite in the Teredo Limestone should be considered "first cycle". Similarly, most of the sponge spicules in the Teredo Limestone, because of their close morphological similarity to those in the Claverley Sandstone, may be reworked. The close textural and compositional similarities between the detrital fractions of the two units, together with the direct evidence for sediment supply from the Claverley Sandstone, suggests that additional extrabasinal sediment sources were insignificant.

6.3 Fells Greensand

Description

The Fells Greensand differs markedly both in texture and composition from the Claverley Sandstone and Teredo Limestone. Whereas each of these two older units are typically represented by a single bed, the Fells Greensand is characterized by numerous thin beds intercalated in limestone or marl.

Grain size varies considerably between outcrops, from bed to bed, and often within individual beds as a result of grading. The modal grain size generally ranges from very fine sand to coarse sand. A float boulder in Deep Creek consisting of very well sorted (20mm) pebbles, which on the basis of catchment geology was almost certainly derived from the Fells Greensand, represents the coarsest grain size. In thin section, the coarsest grains only occasionally reach very coarse sand size (maximum: 1.8mm).

Samples can be divided between those with unimodal or bimodal distributions, with individual modes ranging from moderately to very well sorted. Modes within bimodal samples do not usually display the same degree of sorting. The sediment can also be described as bimodal in terms of the degree of rounding of detrital grains. Detrital sand grains almost invariably become more rounded with increasing grain size, i.e. very fine sand: very angular; fine sand: angular; medium sand: sub rounded to rounded; coarse sand: well rounded to very well rounded.

Within the majority of samples examined, sand grains "float" in cement rather than forming a supportive framework. Grading and lamination, which are common features in outcrop and hand specimen, were rarely observed in thin section, probably because of the relatively coarse grain size of samples chosen for petrographic examination.

The mean composition of the Fells Greensand is given in Table 6.1.1. Quartz is the dominant grain type, comprising an average of 94% of the siliciclastic component for the suite as a whole. The ratio of Qm/Qp is lowest for the coarsest samples and highest in fine to very fine sandstones, i.e. Qm/Qp (cS): 1-5; (mS): 4-10; (fS): 8-29; (vfS): 11-48.

The grain size and angularity of individual crystals within large

Qp grains are approximately equal to Qm grains in the associated finer mode (Figure 6.3.1).

Qm is generally non-undulose and a small percentage of grains contain inclusion trails. Qp crystals display both straight and sutured crystal boundaries. Stretched crystals (straight and sutured) occur in several samples (e.g. JM 104/14, JM 104/18). Many large Qp grains have an internal texture very similar to that of silica-cemented quartzarenites. Worn overgrowths on detrital quartz grains were not observed.

Detrital feldspar comprises an average of 3.0% of the whole rock modal composition. K-feldspar (very fresh microcline or slightly altered orthoclase, in subequal proportions) is twice as abundant as plagioclase (exclusively fresh albite). Perthitic textures were recognized in several cases.

The most abundant type of lithic fragment is chert, which usually occurs as well rounded grains in the very fine to fine sand fraction. Minor amounts of weathered basalt, granite, and myrmekite are present in several samples. The relatively low percentage of lithics (mean: 0.4%) may be a function of many Qp grains not being recognized as rock fragments.

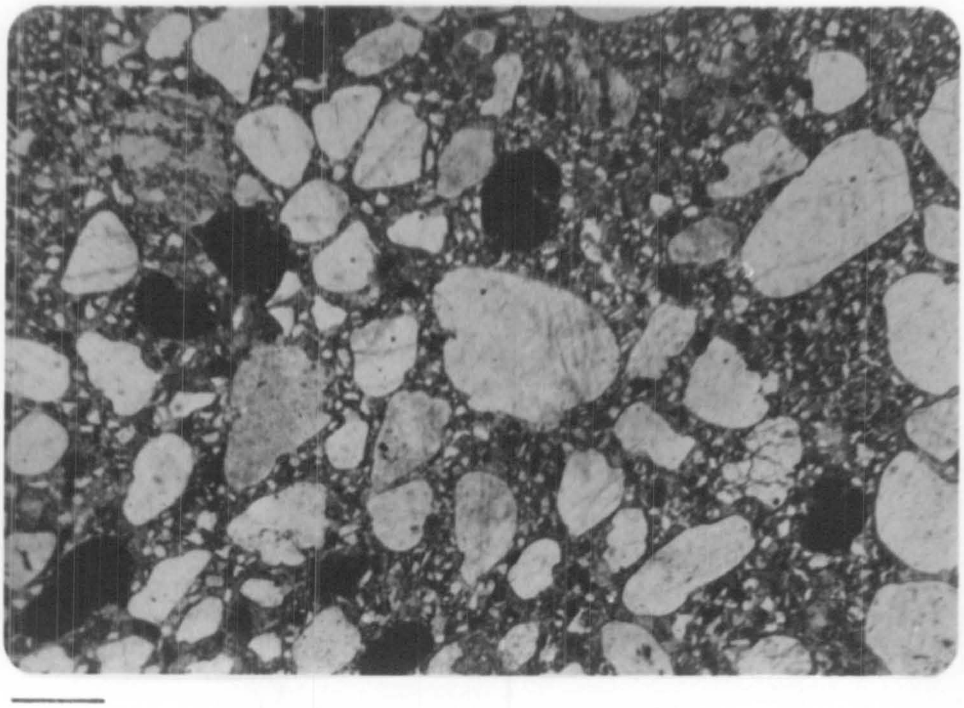
Glauconite is ubiquitous and is commonly a major component (mean: 6.0%). Because the volume of glauconite only exceeds 10% in 2 samples (maximum: 13.2%), the name "greensand" is a misnomer. The majority of unbroken grains are very smooth and well rounded with a random microcrystalline internal texture. Unlike the Teredo Limestone, the grain size of each glauconite mode is about equal to or slightly less than that of the associated detritals. Where more than one detrital sand mode is present, glauconite follows the same pattern.

Phosphatized grains were only recorded in one sample, in very minor quantities.

The Fells Greensand is generally unfossiliferous; most samples are totally devoid of fossil material. Extremely rare and very poorly preserved foraminifera are present in several samples.

Coarse (<1.5mm), blocky calcite is present as an intergranular cement and as veins (1-2mm wide). Very fine, anastomosing veinlets of

Figure 6.3.1a,b: Thin section photomicrograph (a=uncrossed polarizers; b=crossed polarizers) of Fells Greensand (see Appendix III: JM 104/14). Note a) high percentage of detrital quartz; b) bimodal grain size distribution between well sorted, very well rounded coarse sand and very well sorted very angular, very fine sand; c) well rounded glauconite. Scale = 1mm.



6.3.1a

6.3.1b

chert or fine grained, chalcedonic quartz rarely cross-cut larger calcite veins. These veinlets usually penetrate between, rather than actually cutting individual calcite crystals.

The three widely separated samples (refer Appendix III: Table III.d) from the post-Eocene suite of sedimentary dikes (Chapter 4.6b) display few consistent textural features. Their grain size distributions, which range from poorly sorted-unimodal to very well sorted-bimodal, are significantly different from that of the Fells Greensand. Rounding of detrital sand grains varies from very angular to sub-rounded and rounding increases with grain size. The average modal grain size is very fine or fine sand (mean: 0.13mm; max: 0.5mm). The overall mineralogical composition is very similar to that of the Fells Greensand. Differences include a much lower volume of glauconite (mean: 2.7%), and a smaller quartz fraction. Blocky calcite cement is present in approximately the same proportions as in the Fells Greensand.

Interpretation

Texture & Composition

The Fells Greensand can be described in terms of a mixture of two grain populations:

1) well sorted, well rounded, medium to coarse sand.
2) well sorted, angular, very fine to fine sand.

These modes represent texturally supermature and mature sediments, respectively. The combination of two distinct maturity classes indicates a textural inversion that is also observed in bimodal rounding and grain size distributions. Such a textural inversion can be explained either in terms of final depositional processes or multiple sediment source.

A very high degree of mineralogical maturity is evident from the Q:F:L distributions (Figure 6.1.2). Most samples are either quartzarenites or quartz-rich subfeldsarenites. Quartzarenites are commonly inferred to represent the end products of protracted chemical weathering, sorting, and abrasion of sediment in a stable tectonic environment (Pettijohn 1975). Multicyclic processes, which are often invoked but usually difficult to prove, can reduce the need for prolonged weathering (Lewis 1984).

If many of the medium to coarse sand size Qp grains are actually quartzarenite lithic fragments, recycling may have been important. The high degree of rounding of all grains (including feldspars) in the coarse mode indicates that intense or prolonged physical abrasion, rather than chemical weathering, was the final maturing influence for that grain size.

The textural characteristics of the very fine to fine sand mode indicate that it was produced by a different set of processes. Similarities in texture (e.g. Figure 6.3.1), suggest that much of the fine sand size Qm grains were derived from the breakup of larger Qp grains. Breakdown of unstable Qp may have taken place during transportation. This possibility is supported by the high angularity of grains, suggesting that they were not exposed to the same degree of abrasion as the coarse mode.

The corresponding bimodal distribution of well rounded glauconite suggests that the breakdown did not occur during transportation. Two separate sources of quartz sand are required to account for the associated grain size distribution of glauconite. Although compositionally and texturally similar to the fine sand mode, the sedimentary dike suite (Chapter 4.6b) can be eliminated as a source because in several locations dikes cross-cut sediments which are younger than Fells Greensand.

Several samples, which are composed entirely of the fine sand mode, were derived from beds exhibiting features (e.g. flute casts) typical of sediment gravity flows. The implication is that both modes are redeposited together and were mixed at source and/or during transportation.

An integrated model to account for the textural complexities of the Fells Greensand involves a high energy (beach?) environment producing well rounded, medium to coarse quartz sand. Finer angular sand, resulting from the disaggregation of larger polycrystalline grains, was deposited in a lower energy setting (possibly just offshore). Hydraulically equivalent glauconite accumulated in each area. The two modes were mixed during transportation to the site of accumulation.

Provenance

The first standard deviation field of Q:F:L data for the Fells Greensand (Figure 6.1.3) falls within the "continental block" provenance field of Dickinson & Suczek (1979). However, the Qm:F:Lt plot indicates a "recycled orogen" provenance. It is difficult to distinguish which of these fields is more appropriate for the Fells Greensand. Prolonged peneplanation since the Rangitata Orogeny (Gair 1967), in the absence of significant tectonic activity, may have given the source area a cratonic-like aspect.

The presence of fresh microcline, granite, and myrmekite fragments suggests that granitoids may have been an additional direct source. The character of the polycrystalline quartz reveals little of the original source rocks. Many of the grains show features common in metamorphic quartzites, silica-cemented quartzarenites, vein quartz, and granites. It is possible that much of the detrital quartz represents reworked quartz-rich sandstones associated with coal measures. Although no in situ deposits are known from Marlborough, such sediments are common elsewhere in Paleogene sequences of New Zealand (Suggate 1950, 1978) and their correlatives may have been available for erosion and recycling in Late Eocene times.

Chapter Seven

SUMMARY AND CONCLUSIONS

7.1 Geologic History: Late Cretaceous To Late Oligocene

Piripauan

A transgression, which followed a prolonged period of uplift, subaerial erosion and non-deposition, commenced in Marlborough during mid-Piripauan times. Freshwater to very shallow water marine sands (*Okarahia Sandstone*) were deposited in southern Marlborough, while (deeper?) marine glauconitic sands (*Paton Formation*) were deposited to the north. Non-deposition and possible subaerial exposure continued in central Marlborough (Figure 7.1).

Haumurian - Teurian

Continued transgression allowed deposition of marine silts (*Woolshed Formation*) during earliest Haumurian times. This facies was deposited in shallow water (inner shelf) in southern and central areas, but in a somewhat deeper setting in the north. Intercalated flysch-like sands were restricted to northern regions. A NW-trending belt of deeper water (outer shelf to bathyal) carbonate ooze (*Mead Hill Formation*), representing the initiation of Amuri Limestone deposition, began to accumulate in the deepest part of the basin during the mid Haumurian (Figure 7.2).

A minor regression in the late Haumurian, which was accompanied by a minor episode of folding and clastic dike intrusion, resulted in submarine erosion throughout central and southern Marlborough. The unconformity surface was covered by shallow marine (inner shelf) sands (*Claverley Sandstone*). The deeper water facies equivalent of this regressional sand was silty, siliceous ooze (*Lower Chert Member*) (Figure 7.3).

Subsequent transgression resulted in outward migration of the carbonate ooze facies into shallow water (inner shelf) to the north and south. A basin-wide paraconformity (K/T boundary), which separates uppermost Haumurian from mid Teurian sediments, may locally represent a period of non-deposition of c.3.5 million years. Sedimentation recommenced with widespread deep water (bathyal), carbonate ooze accumulation (Figure 7.4).

Waipawan - Porangan

A phase of folding and clastic dike intrusion, followed by active submarine erosion, non-deposition, and phosphatic hardground formation commenced in mid Waipawan times. This unconformity (*sub-Teredo Limestone unconformity*) was covered by a veneer of deep water (bathyal) sandy glauconitic foraminiferal ooze (*Teredo Limestone*) in southern and central areas, and by silty, siliceous ooze (*Upper Chert Member*) in northern Marlborough (Figure 7.5). These initial post-unconformity sediments began to accumulate in the late Waipawan in the north, and early Mangaorapan in the south. Non-deposition continued in central areas, until late Mangaorapan or earliest Heretaungan.

Deep water (bathyal) carbonate ooze accumulation was reinitiated in latest Waipawan times, with the deposition of a marly facies (*Lower Marl*) in central areas; and a purer micritic facies (*Lower Limestone*) in northern areas (Figure 7.6). The marly facies had extended throughout central and northern Marlborough by latest Mangaorapan or earliest Heretaungan times. Fine grained carbonate deposition in southern Marlborough, recommenced in the early Mangaorapan with a pure micritic ooze (*Middle Limestone*). This pure carbonate facies became established throughout Marlborough, from mid Heretaungan to late Porangan times (Figure 7.7).

Bortonian - Runangan

In mid Bortonian times, limestone deposition was replaced by a basin-wide marly facies (*Upper Marl*) (Figure 7.8). The transition was accompanied by a minor influx of extra-basinally derived quartzarenites (*Fells Greensand Member*). A pulse of volcanism (*Grass Seed Volcanics*) during the late Bortonian caused basaltic tuffs and minor pillow lavas to be deposited locally in northern and central Marlborough. Marl-dominated ooze accumulation continued until at least late Runangan (latest Eocene) times. If Amuri Limestone deposition continued into the Whaingaroan (Early Oligocene) in Marlborough, then it has been subsequently eroded.

Whaingaroan - Waitakian

The earliest record of post-Amuri Limestone sedimentation occurs in southern inland Marlborough, where late Whaingaroan submarine basaltic tuffs and lavas (*Cookson Volcanics*) overlie a disaggregated hardground (*Phosphatic Conglomerate Bed*) (Figure 7.9). This hardground developed on a major erosional unconformity surface marking the cessation of Amuri

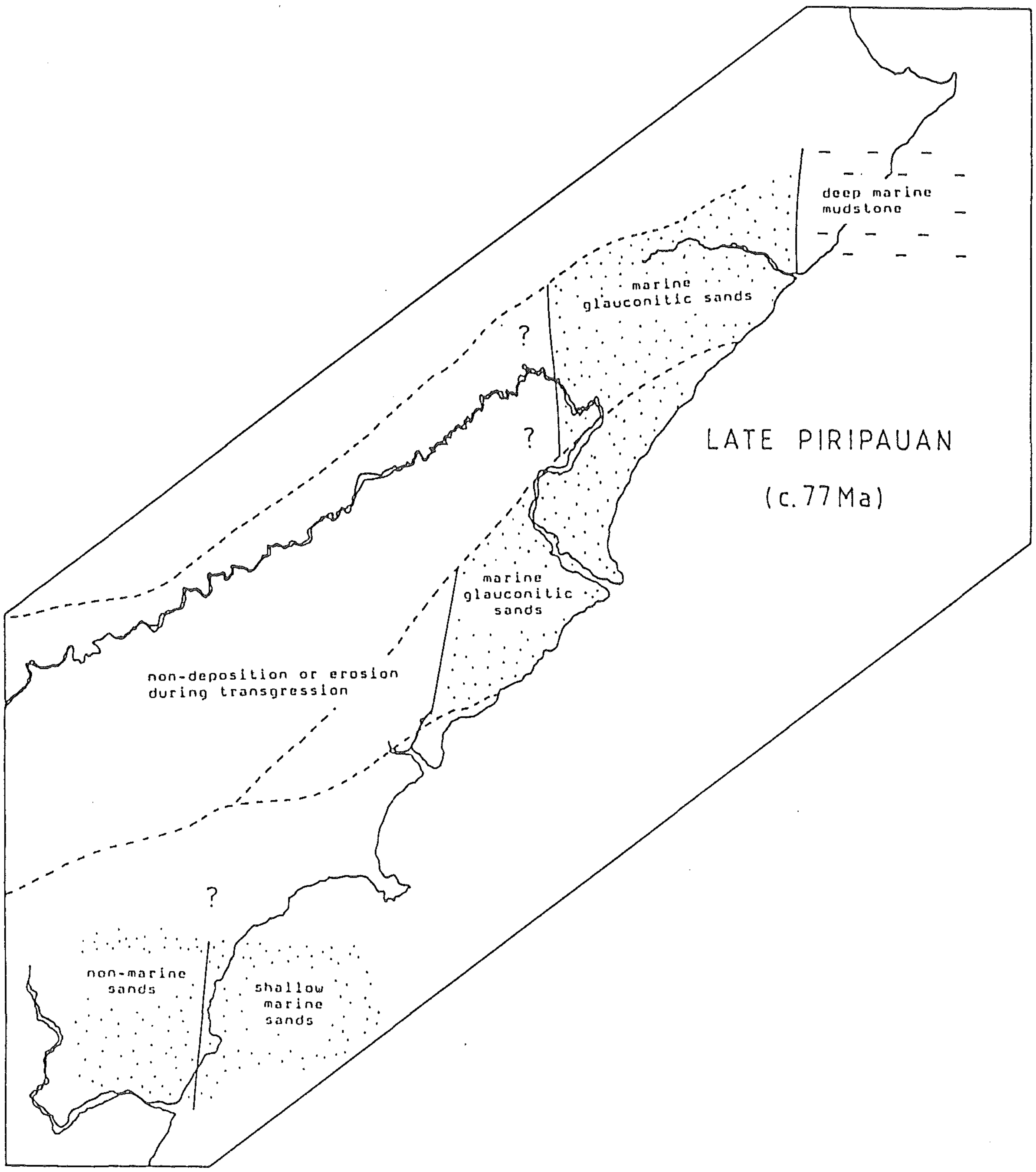


Figure 7.1: Paleolithofacies map in late Piripauan time (c.77Ma).

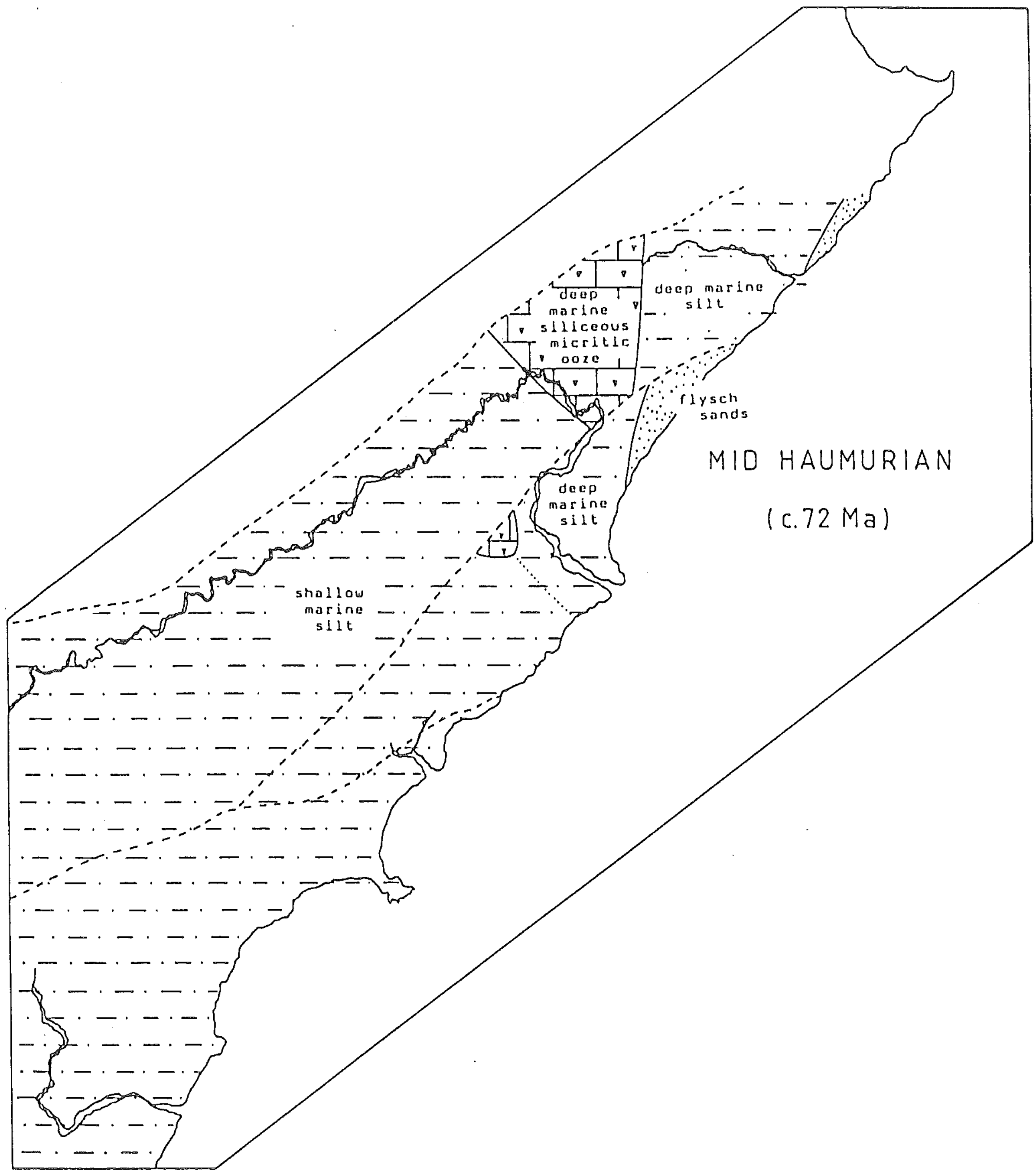


Figure 7.2: Paleolithofacies map in mid Haumurian time (c.72Ma).

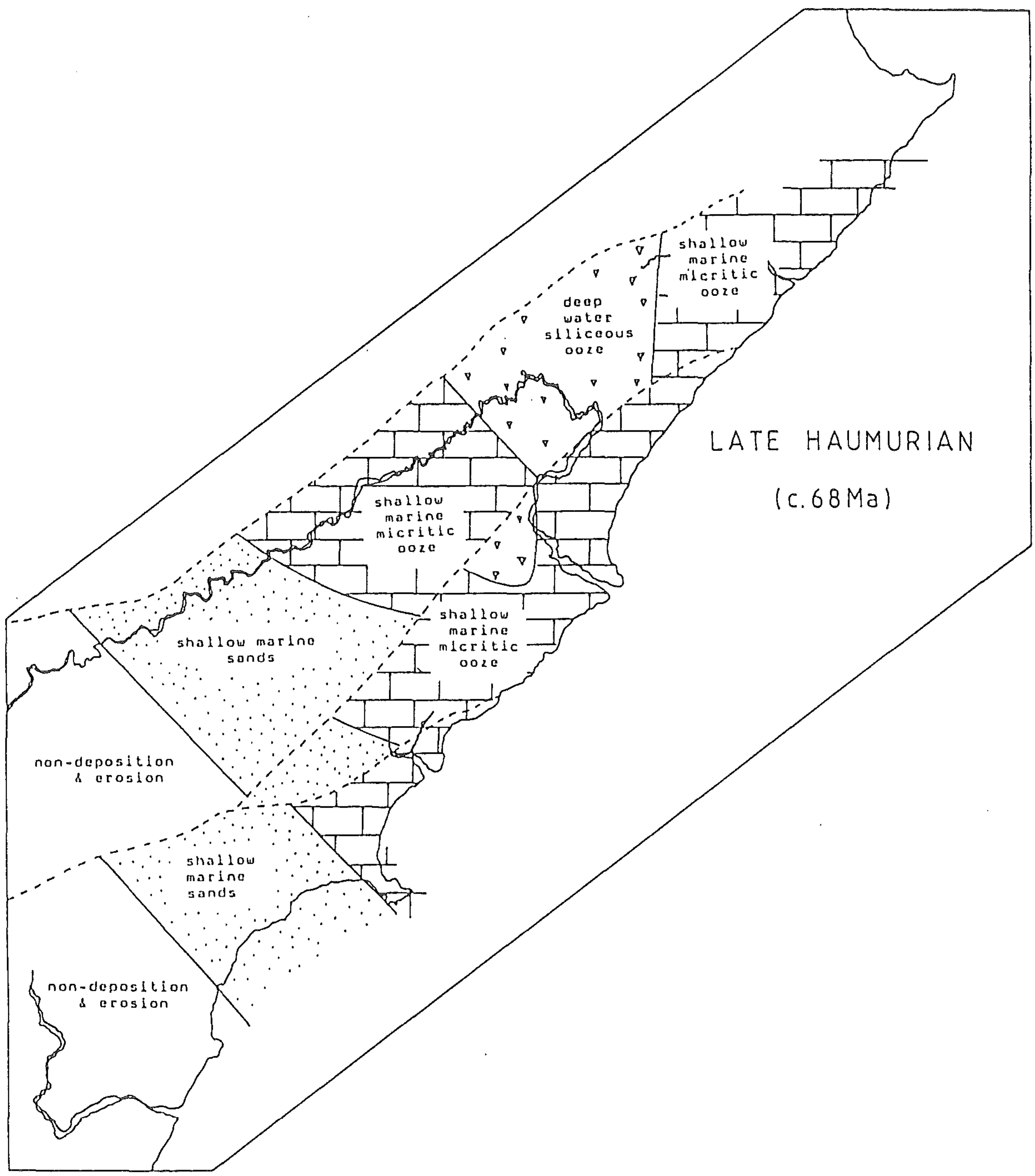


Figure 7.3: Paleolithofacies map in late Haumurian time (c.68Ma).

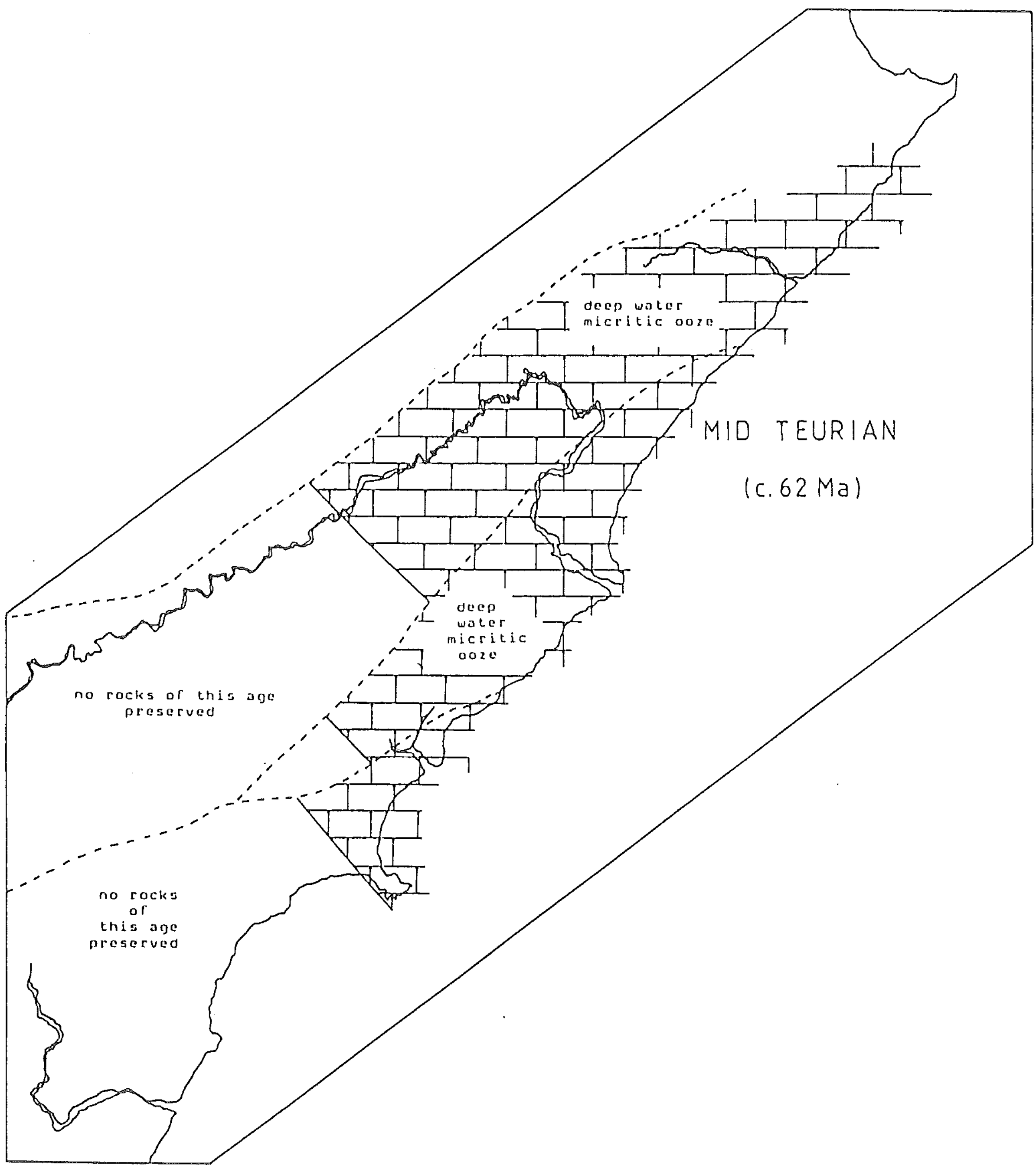


Figure 7.4: Paleolithofacies map in mid Teurian time (c.62Ma).

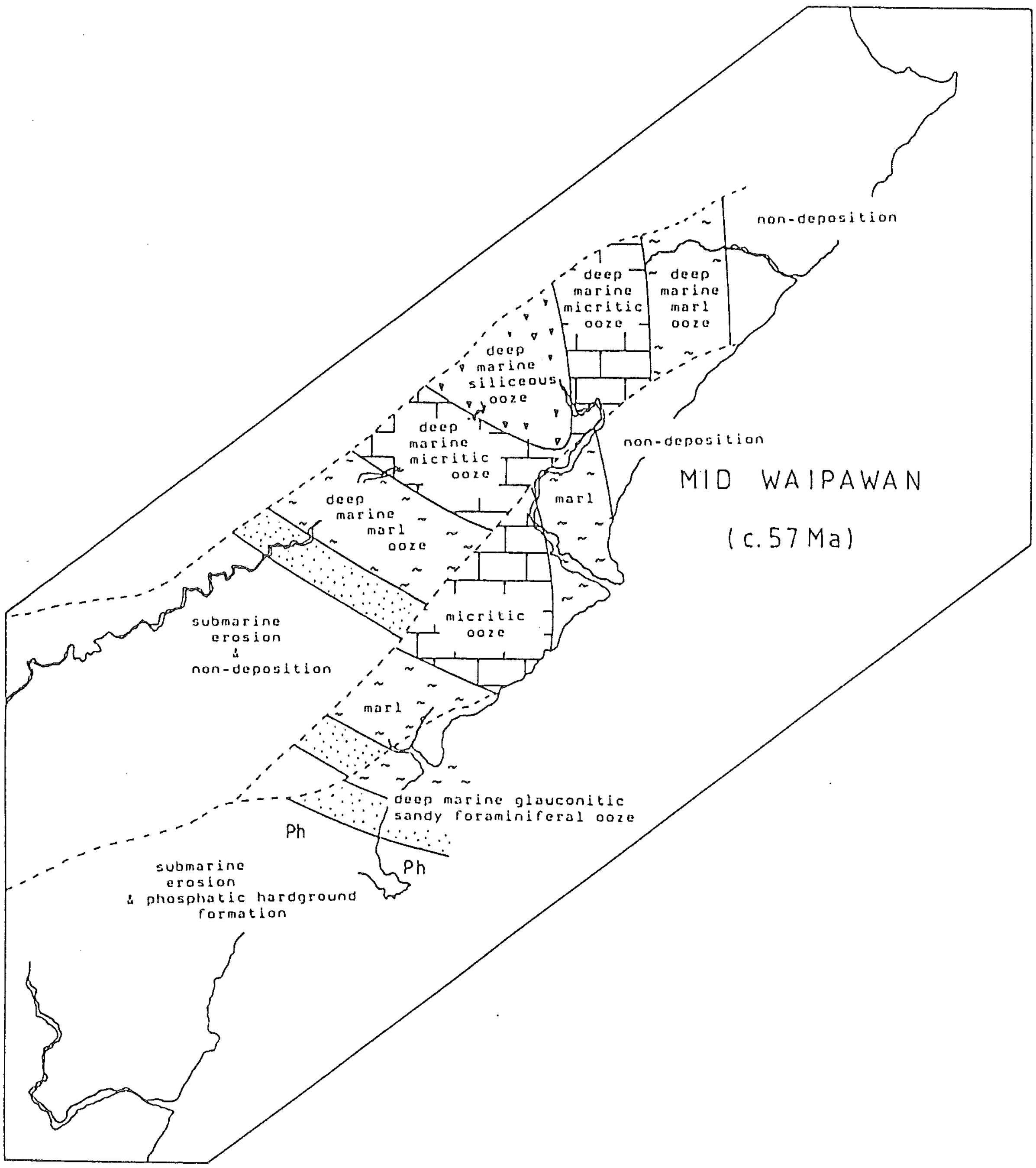


Figure 7.5: Paleolithofacies map in mid Waipawan time (c.57Ma).

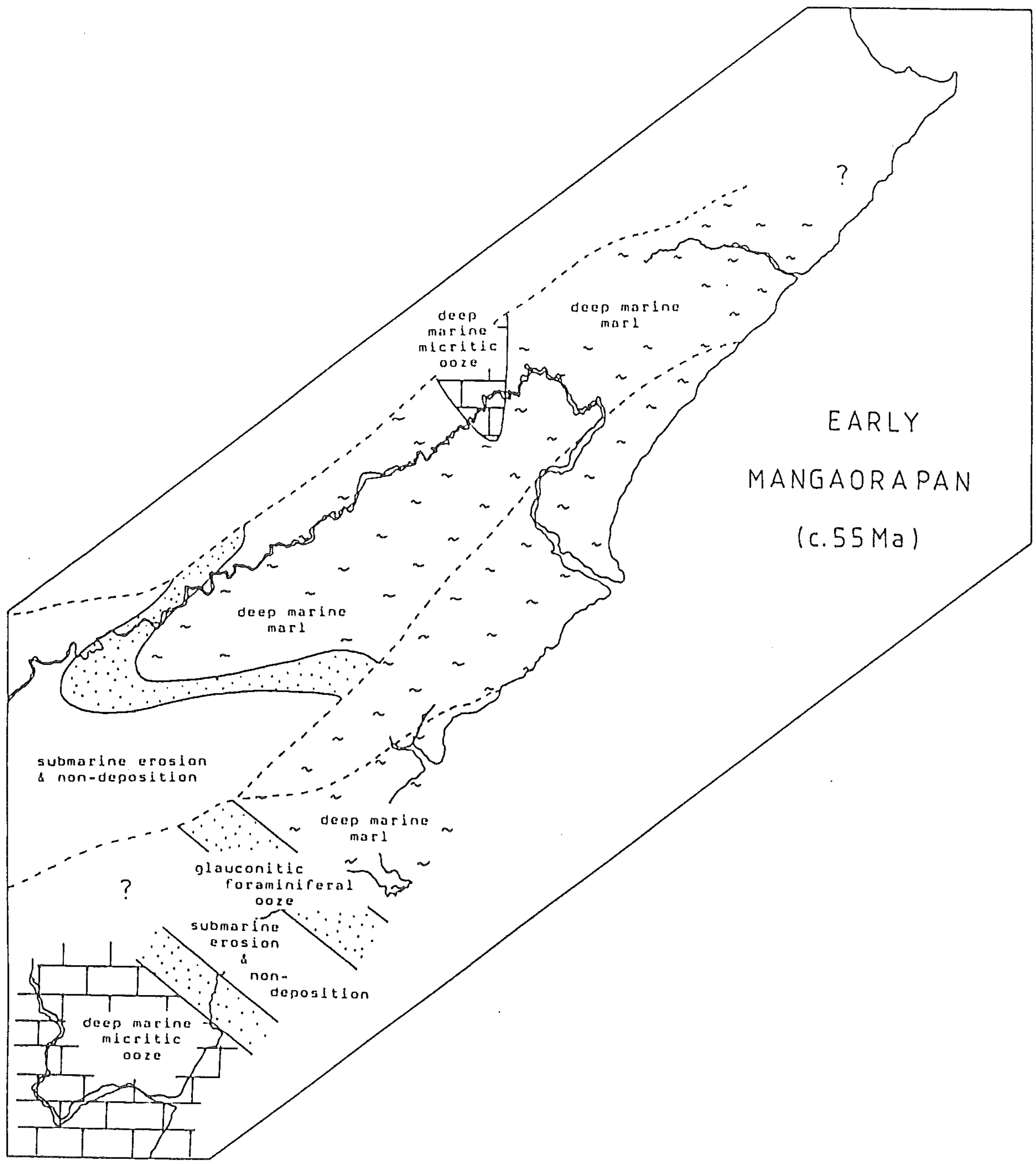


Figure 7.6: Paleolithofacies map in early Mangaorapan time (c.55Ma).

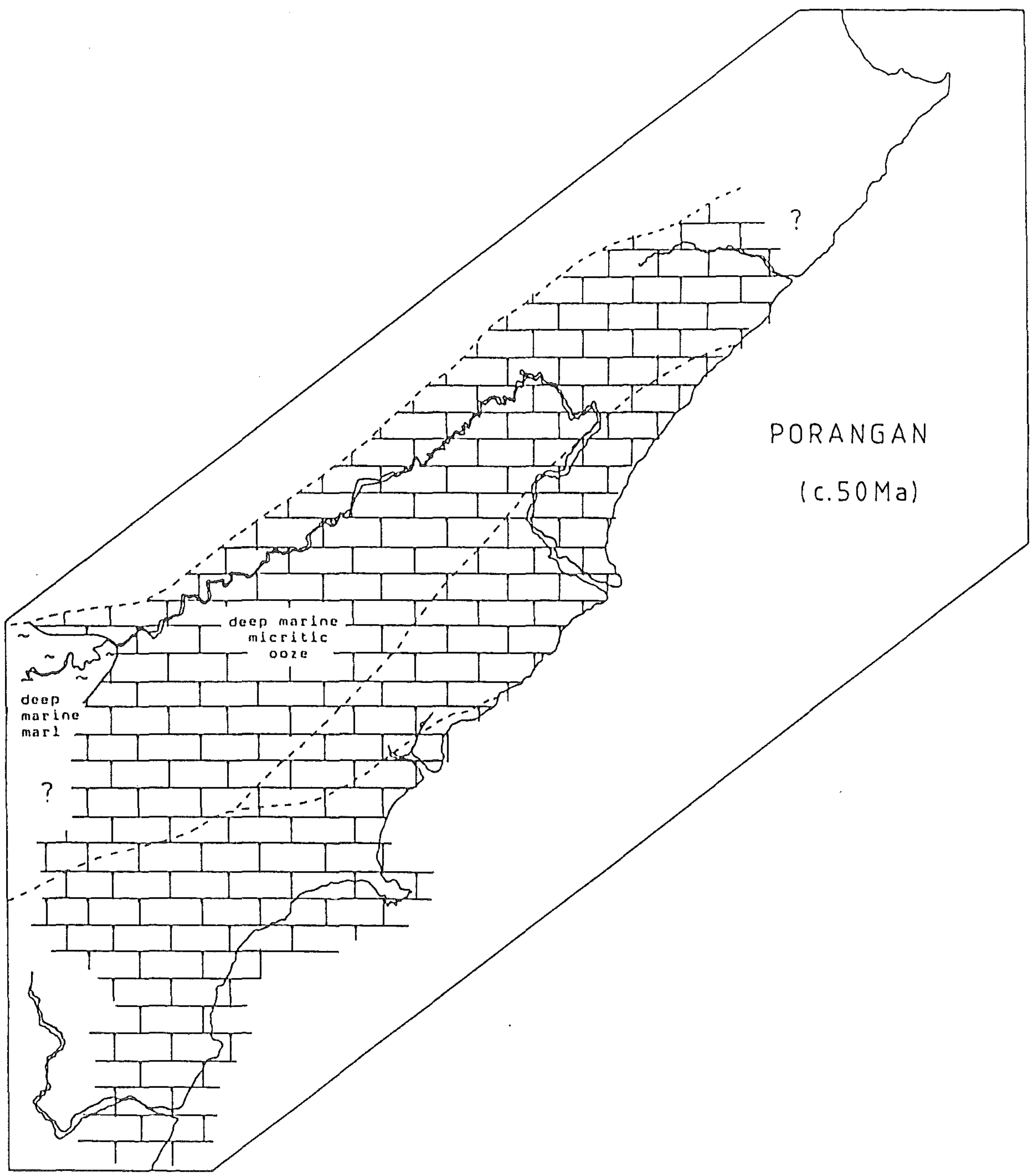


Figure 7.7: Paleolithofacies map in Porangan time (c.50Ma).

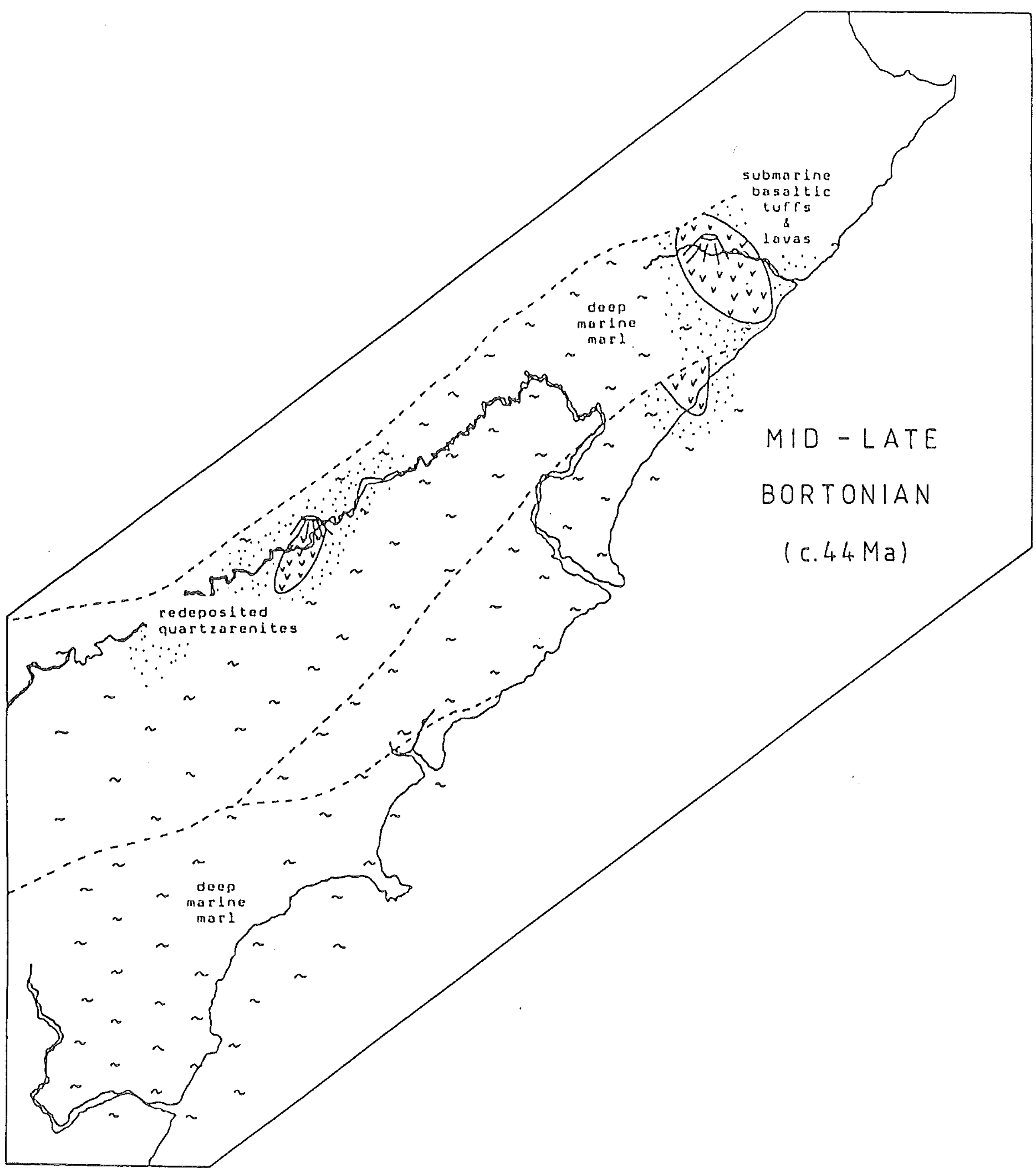


Figure 7.8: Paleolithofacies map in mid to late Bortonian time (c.44Ma).

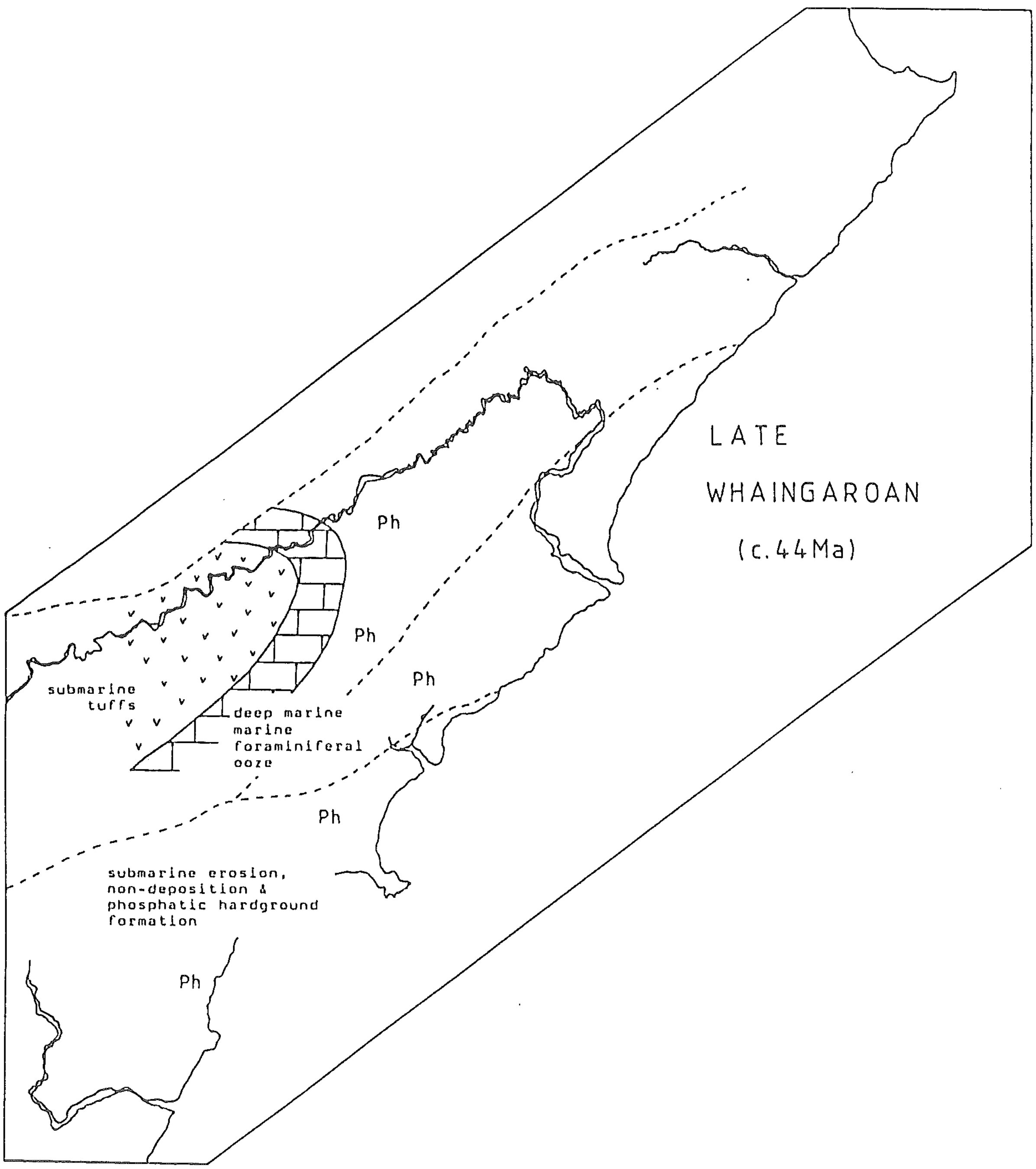


Figure 7.9: Paleolithofacies map in late Whaingaroan time (c.30Ma).

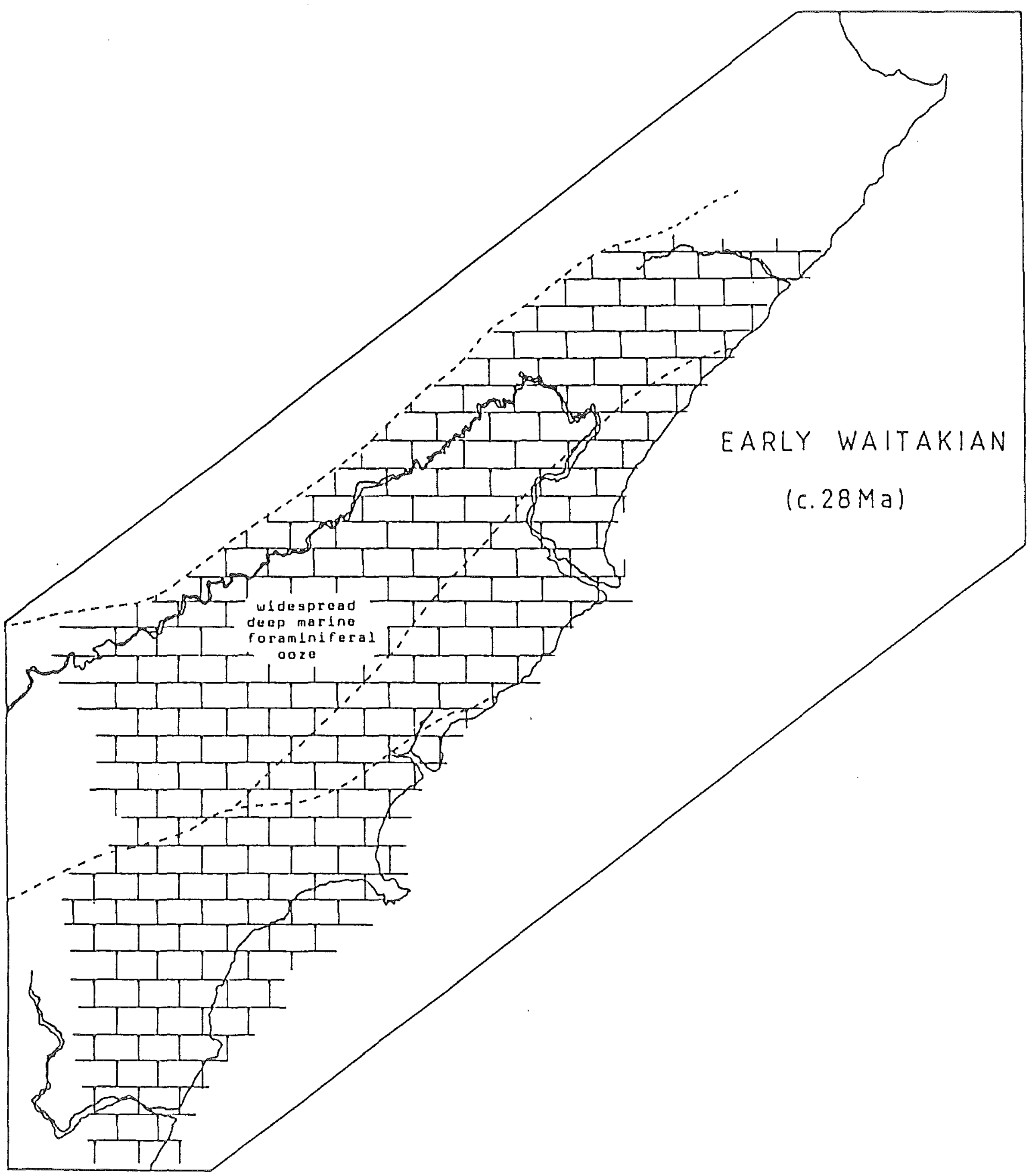


Figure 7.10: Paleolithofacies map in early Waitakian (c.28Ma).

Limestone deposition. Folding and possible clastic dike intrusion accompanied and/or preceded erosion.

Non-deposition continued elsewhere in Marlborough until early Waitakian times. A glauconitic foraminiferal ooze, which began to accumulate in southern inland areas during the late Whaingaroan, had become widespread throughout Marlborough by early Waitakian times (Figure 7.10).

7.2 Sedimentation Patterns

Basin Morphology

Facies relations and isopach patterns indicate that the Amuri Limestone began to accumulate within a NW-trending trough (5-10km wide) that developed near Swale Stream. Between mid Haumurian and mid Waipawan times, this trough gradually widened (20-30km) and its axis migrated c.10km SE. During this period, the trough was bounded by an extensive near-horizontal platform which gradually subsided from inner shelf to bathyal water depths. The platform and trough maintained their position and morphology until at least latest Eocene times.

The maintenance of the trough over such a prolonged period indicates continued basin subsidence. The axis is parallel to the probable trend of known growth faults which are inferred to have been active during the mid Cretaceous. Reactivation of these older features is likely to have been an important control on local subsidence. Judging from the lack of evidence for steep sea floor gradients, it is unlikely that subsidence was rapid.

Although more detailed work is warranted on units underlying the Amuri Limestone (e.g. Woolshed Formation), it appears that the trough, and its accompanying lateral facies changes, developed on and parallel to an earlier slope break.

Spatial Distribution Of Facies

The areal distribution of sediment types was directly controlled by the position of the central trough. Platform calcilutites have a higher terrigenous component, are more thinly bedded, and contain more sand size material than deeper water coeval deposits. Periods of non-deposition and erosion are represented by disconformities or angular unconformities which are overlain by sandy facies (Claverley Sandstone, Teredo Limestone). Strong bottom currents in these areas are inferred to have been the main cause of erosion. Prolonged non-deposition favoured accumulation of glauconite, phosphatization, and widespread development of a *Thallasinoides* ichnofauna.

Corresponding breaks in sedimentation within the trough are less apparent and there is little evidence for active erosion. Erosional unconformities and their overlying sandy facies on the platform pass laterally into paraconformities and highly siliceous, pyritic, non-calcareous muds (Lower and Upper Chert Members) within the trough. Deeper water areas were apparently protected from the effects of winnowing bottom-scouring currents and the period of non-deposition was of lesser duration. Non-depositional indicators which characterize platform areas (e.g. glauconite, phosphate, *Thallasinoides*) are absent within the trough. Diagenetic overprinting by chert and dolomite is almost entirely restricted to sediments deposited within the trough.

Temporal Sedimentation Patterns

Temporal trends in Amuri Limestone sedimentation can be recognized at three levels:

1. A supersequence (c.50m.y. duration) deposited during an inter-regional transgression, beginning in the Late Cretaceous (Piripauan) and continued into the Oligocene, which can be recognized in many areas throughout New Zealand (e.g. Wilson 1956; Stevens & Suggate 1978). In eastern New Zealand, this transgression can be linked to subsidence of the passive continental margin subsequent to the rifting of New Zealand from Gondwana.

2. Superimposed on this transgressive supersequence are regional stratigraphic sequences of lesser duration (c.12m.y.) (Figure 7.11). These sequences are inferred to result from periodic tectonism within the basin. The full development of a complete sequence is outlined below:

   a. Cessation of sedimentation, tectonic uplift and local regression, folding and clastic dike intrusion, erosion and unconformity development. Basaltic volcanism may be associated with the tectonic pulse.

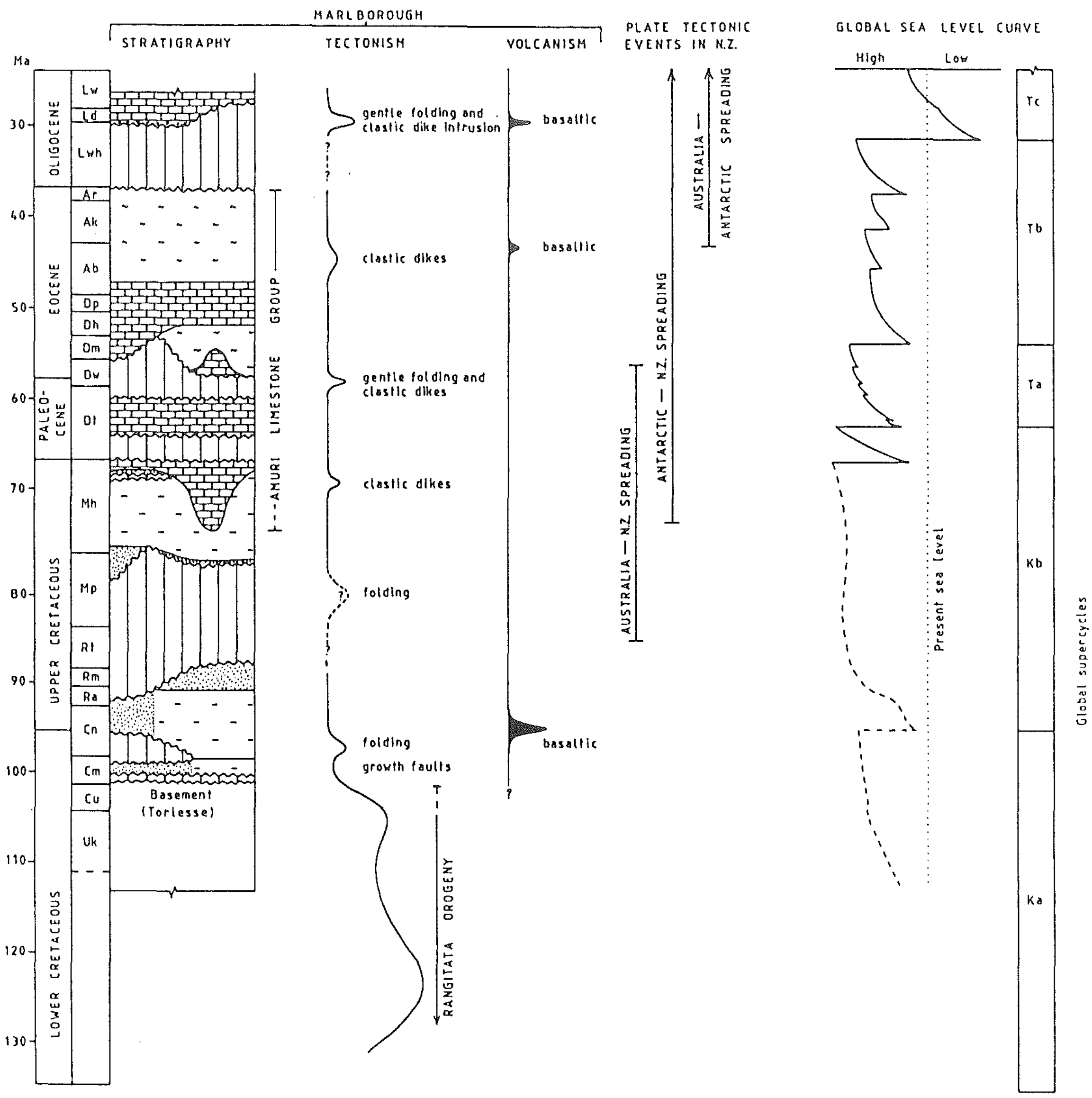


Figure 7.11: Diagrammatic summary of the Upper Cretaceous and Paleogene stratigraphy, tectonism, and volcanism in eastern Marlborough; compared with major plate tectonic events affecting the New Zealand region, and global sea level changes (after Vail et al. 1977) during that period.

b. Widespread accumulation of a sandy glauconitic facies in marine environments.

c. Fine grained sedimentation.

3. The effects of global sea level changes (c.5m.y.) may be superimposed on the regional sequences (e.g. K/T boundary paraconformity; Lower Marl regressive/transgressive cycle).

Origin Of The Non-Carbonate Fraction

The extremely high SiO_2 content of calcilutites and marls within the Amuri Limestone, and partly coeval mudstones within the Woolshed Formation, is an important lithologic feature. It is unknown whether the excess silica was deposited within the sediment during its accumulation or if it was introduced diagenetically from an exterior source (for discussion see M. Lawrence, in prep.). If the silica is in situ, then it suggests that special chemical conditions prevailed during the period of deposition. Such conditions might include abundant fine or dissolved silica being shed from an adjacent landmass undergoing intense chemical weathering. Alternatively, high productivity of siliceous plankton in the surface waters may have contributed amorphous silica directly to the sediment.

The first alternative is supported by widespread, contemporaneous peneplanation of the emergent landmass during the Late Cretaceous and Paleogene (Stevens & Suggate 1978). There is little evidence to support a dominantly biogenic origin because of the relative lack of siliceous microfossils. If siliceous organisms were major contributors to the silica budget, then they have been completely dissolved and reprecipitated.

Several possible external sources for silica can be considered. Dewatering of the underlying and laterally correlative Woolshed Formation is an obvious possibility. Alteration of volcanics may account for the high silica content in some of the Eocene age Amuri Limestone. However, there are no known volcanics of Late Cretaceous or Paleocene age with which to supply silica to the Mead Hill Formation in which the bulk of the silicification occurs.

An ultimately terrigenous source for most of the excess silica in the Amuri Limestone is favoured, because of the widespread occurrence of highly siliceous deposits (irrespective of host lithology) of similar age throughout New Zealand (Moore 1983).

Although illite and locally kaolinite occur in minor quantities, the dominant clay mineral throughout the Amuri Limestone is smectite. Fergusson (1985) concluded that the smectite was not derived from the in situ alteration of volcanic ash falls and was unlikely to have formed from transported ash. The main reasons that were cited in support of this conclusion include:

1. The absence of sedimentary structures (e.g. grading, cross bedding).

2. The absence of a contemporaneous volcanic source.

3. The paucity of volcanically derived minerals in the sand fraction.

The absence of sedimentary structures only provides evidence against a primary ash fall origin. These features would not be expected if the smectite was reworked from a volcanic source by very low energy processes and deposited by hemipelagic settling.

Previously unrecognized widespread volcanic deposits (Woodside Formation and Grass Seed Volcanics), which are partly coeval with the smectite-rich Formations (Lower Marl and Upper Marl) in the Amuri Limestone, provide a logical volcanic source.

The absence of sand size volcanic detritus is the major remaining argument against a volcanic origin for the smectite. The almost total lack of primary volcanic detritus in calcilutites and marls immediately adjacent to the intercalated volcanics shows that the extrusives in these areas were not being reworked. In addition, there is no known coeval volcanic source for the smectite which is present throughout the rest of the Amuri Limestone.

Smectite also occurs in the clay mineral fraction of the Woolshed Formation, but in association with subequal amounts of kaolinite and illite. However, the Mead Hill Formation, which is coeval with the upper part of the Woolshed Formation, contains neither of these minerals. There is no apparent reason why deposition of illite and kaolinite should not have extended laterally into the Mead Hill Formation.

It is suggested that some of the smectite within the Amuri Limestone is derived from the conversion of illite (and possibly kaolinite) . This conversion may be an important part of the silicification process in the Amuri Limestone. Onshore volcanic deposits, coeval with those within the Amuri Limestone, remain a possible additional source for the smectite. Large distances and mode of transportation might help explain the absence of volcanically derived sand. No such volcanics are known in areas immediately south but they may have been present to the west of the study area where the Late Cretaceous - Early Tertiary succession has been subsequently eroded.

Detrital sand associated with the Amuri Limestone is concentrated at three main stratigraphic horizons: Claverley Sandstone, Teredo Limestone, and Fells Greensand. The accumulation of these units was coeval with, or immediately followed, unconformity development and/or minor tectonic activity.

In the case of the Claverley Sandstone and Teredo Limestone, the detrital sand fraction was intra-basinally derived from the underlying units. Direct erosion and exposure of the older source rocks, together with submarine extrusion of remobilized sediment via clastic dikes, were important mechanisms for sediment supply. The dominant source for the Claverley Sandstone is likely to have been the Woolshed Formation. The Claverley Sandstone was locally exhumed and elsewhere remobilized at depth and extruded to provide a source of detrital sand for the Teredo Limestone.

An extra-basinal source for the Fells Greensand is most likely. The texture and composition of the redeposited supermature quartzarenites is distinct from any older intra-basinal clastic units. There is little evidence for significant contemporaneous erosion or clastic dike intrusion within the basin. Possible terrigenous sources include reworked Late Cretaceous - Early Tertiary quartzose coal measures which may have been exposed to the south and west (e.g. Broken River Formation).

Plate Tectonic Effects

The initiation of Late Cretaceous transgression may be related to subsidence following the initial rifting of New Zealand from Gondwana.

Laird (1981) has related the active block-faulting and half-graben formation, which typifies the Late Cretaceous sequence of western New Zealand (e.g. Knox 1982; Nathan et al. 1986), to this rifting. Distinct compressional tectonic pulses are recognized during the late Haumurian, mid Waipawan, mid Bortonian, and late Whaingaroan in Marlborough. These events may be the distal equivalents of the more vigorous activity elsewhere.

The late Haumurian event shows no apparent correlation to major plate tectonic events affecting the New Zealand region. However, tectonism during the mid Waipawan is coincident with the cessation of spreading between New Zealand and Australia. The resultant changes in stress are inferred to have been accommodated by a brief reactivation of pre-existing (? mid Cretaceous) basement faults.

The mid Bortonian event coincides with an acceleration in the rate of spreading between Australia and Antarctica. If this change in spreading rates can be related to the mid Bortonian event, then the large distances from Marlborough may account for the mild nature of tectonism relative to the other three events. However, the association is considered unlikely because of the associated basaltic volcanism which cannot be readily explained in terms of such distant activity.

As suggested in Chapter 5, the mid Whaingaroan event is likely to have resulted from the initial propagation of an Australian - Pacific plate boundary through New Zealand.

The very large distances from the active centres of plate tectonic activity during the Late Cretaceous and Paleogene may largely account for the generally lack of intensity of tectonic activity in Marlborough. These distances may have filtered out "noise" that was represented, in areas closer to spreading centres (e.g. West Coast of New Zealand), by more continuous and active tectonism. The timing of at least three of these events may therefore provide an independent estimate for the timing of large-scale plate tectonic events.

7.3 Corollary: Transcurrent Displacement On The Hope And Kekerengu Faults.

An implicit result of this study has been an approximation of the amount of transcurrent displacement across several major Marlborough faults (Figure 1.5). Most offsets are between extrapolated facies boundaries or isopachs and are approximate to within the limits shown below. Judging from the development of facies in the Amuri Limestone, there has been no detectable movement on the Hope or Kekerengu Faults between the Late Cretaceous and Late Eocene. Although not studied in the same detail, there is no evidence in the distribution of post-Amuri Limestone Oligocene sediments to suggest pre-Late Oligocene movement.

The dextral offset across the segment of the Hope Fault, north of its junction with the Kekerengu Fault, is 5-10km; 10-15km of dextral movement can be demonstrated on the Kekerengu Fault. Cumulative movement on these two faults, south of their junction, is 15-25km. This estimate is in close agreement with that of Freund (1971), who calculated an offset of 12 miles (20km) on the main branch of the Hope Fault. Very little or no transcurrent movement can be recognized across the Fidget Fault.

Lateral variations in offsets along the faults can be attributed to basement/cover decollements (Prebble 1980). More accurate estimates on fault displacement should therefore be made from offsets in basement geology. A much better understanding of facies trends within the Torlesse Supergroup in Marlborough than presently exists will probably be required to further constrain the amount of transcurrent movement.

7.4 Suggestions For Further Work.

1. External recognition and interregional correlation of the late Haumurian, mid Waipawan, and mid Bortonian unconformities.

2. External recognition and interregional correlation of tectonic pulses in the late Haumurian, mid Waipawan, and mid to late Bortonian.

3. External recognition and interregional correlation of the internal lithostratigraphic units or their facies equivalents within the Amuri Limestone.

4. A regional study of the Upper Iwitahi Group with special attention to the Late Cretaceous transgression

at the base of the Woolshed Formation.

5. A regional study of the Coverham and Lower Iwitahi Groups in Marlborough.

6. A geochemical, petrological and volcanological study of the Grass Seed Volcanics Member.

7. A detailed study of the tectonostratigraphic relationships of the Woodside Formation to the rest of the Amuri Limestone Group.

8. A study of basement faults, which were active in the mid Cretaceous, with the aim of recognizing possible reactivation controlling later basin development. An area in which such faults should be present is near Branch Stream where a major bathymetric/lithofacies break occurs.

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APPENDIX I: MICROPALEONTOLOGICAL AGE AND ENVIRONMENTAL DETERMINATIONS

N.B. Additional data available from NZ Fossil Record File (NZ FRF)

KEY

*	Unconformably truncated
!	Directly overlies Teredo Limestone
!!	Unconformably overlies Amuri Limestone
#	Age determination not available prior to thesis completion
ND	Non determinable
NF	Non fossiliferous
B	Base of formation
M	Middle part of formation
T	Top of formation
LCM	Lower Chert Member
UCM	Upper Chert Member
FLM	Flaxbourne Limestone Member
PCB	Phosphatic Conglomerate Bed
GV	Intercalated with Grass Seed Volcanics
RM	Red Marl

Numbers listed in Field No. column indicate collection and examination as part of this study.

APPENDIX I: Micropaleontological Age & Environmental Determinations

NZ FRF No.	Field No.		Formation	Location	Stage	Environment
S36/f1030			Woolshed Formation	Needles Point	Mh	
S42/f523			Woolshed Formation	Limestone Hill	Mh	
S36/f1057			Woolshed Formation	Chancet Rocks	Mh	Bathyal
S36/f1029			Woolshed Formation	Needles Pt	Mh	Bathyal
S36/f702			Woolshed Formation	Ess Creek	Mh	
S36/f611			Woolshed Formation	Ben More Stm	Mh	
S41/f566			Woolshed Formation	Seymour Stm	Mh	
O31/f121			Woolshed Formation	Kaikoura Pnsla	Mh	Inner shelf
S41/f567			Woolshed Formation	Seymour Stream	Mh	
O31/f138			Woolshed Formation	Kaikoura Pnsla	Mh	
O30/f119	43/20		Woolshed Formation	Muzzle Stream	Mh	
S36/f650			Woolshed Formation	Woodside Creek	Mh	
P29/f195		T	Woolshed Formation	Chancet Rocks	Mh	
O31/f100		T	Woolshed Formation	The Fell	Mh	
O31/f56		T	Woolshed Formation	Seymour Stream	Mh	
S41/f568		T	Woolshed Formation	Seymour Stream	Mh	
S42/f541		T	Woolshed Formation	Branch Stm	Mh	
S42/f511		T	Woolshed Formation	Bluff Stm (lower)	Mh	
O30/f120	42/3	T	Woolshed Formation	Dart Stream	Mh	Inner shelf
S36/f600		T	Woolshed Formation	Ben More Stm	Mh	
S41/f503		T	Woolshed Formation	Seymour Stream	Mh	
S36/f600		T	Woolshed Formation	Ben More Stm	Mh	
O31/f70		T*	Woolshed Formation	The Fell	Mh	Inner shelf
O31/f231	501/2	T*	Woolshed Formation	Monkey Face	Mh	
O31/f230	501/1	T*	Woolshed Formation	Monkey Face	Mh	
S42/f669		B	Claverley Sandstone	Dead Horse Gully	Mh	
S56/f518A		B	Claverley Sandstone	Haumuri Bluff	Mh(upper)	

APPENDIX I: Micropaleontological Age & Environmental Determinations

NZ FRF No.	Field No.		Formation	Location	Stage	Environment
030/f55	12/1	M	Claverley Sandstone	Bluff Stm (lower)	NF	
S42/f681		M	Claverley Sandstone	Branch Stream	Mh	
P31/f40	25/9	T	Claverley Sandstone	Puhi Puhi River	Mh	
030/f49	10/3	T	Claverley Sandstone	Dart Stream	NF	
S36/f1032			Mead Hill (FLM)	Weld Cone	Mh	
S36/f1003			Mead Hill (FLM)	Flaxbourne River	Mh	Bathyal
S36/f1045			Mead Hill (FLM)	London Creek	Mh	
S36/f1028			Mead Hill (FLM)	Needles Point	Mh	Bathyal
S36/f1017			Mead Hill (FLM)	Flaxbourne River	Mh	Bathyal
030/f138	50/4	B	Mead Hill	Bluff Stm (upper)	Mh	Inner shelf
S42/f664		B	Mead Hill	Bluff Stm (upper)	ND	
030/f142	50/5	B	Mead Hill	Bluff Stm (upper)	Mh	Inner shelf
030/f136	42/1	B	Mead Hill	Dart Stream	Mh(upper)	Mid shelf
030/f56	12/2	B	Mead Hill	Bluff Stm (lower)	Mh(upper)	Inner to mid shelf
S42/f670		B	Mead Hill	Dead Horse Gully	ND	
S42/f676		B	Mead Hill	Muzzle Stream	ND	
030/f137	52/3	B	Mead Hill	Bluff River	Mh	Inner shelf
031/f181	1/3c	B	Mead Hill	Kaikoura Pnsla	Mh	Inner shelf
030/f50	10/1	B	Mead Hill	Dart Stream	Mh(upper)	Mid shelf
031/f177	4/3	B	Mead Hill	Kaikoura Pnsla	Mh	Inner shelf
S36/f1039		B	Mead Hill	London Creek	Mh	
P30/f286	30/5	B	Mead Hill	Mead Stream	Mh	
S36/f682		M	Mead Hill	Needles Point	Mh	
P30/f274	30/14	M	Mead Hill (LCM)	Mead Stream	Mh	
S36/f631		M	Mead Hill	Woodside Creek	Dt-Dw	
P30/f268		M	Mead Hill	Woodside Creek	Dt	
P30/f267		M	Mead Hill	Woodside Creek	Mh	

APPENDIX I: Micropaleontological Age & Environmental Determinations

NZ FRF No.	Field No.		Formation	Location	Stage	Environment
P30/f269		M	Mead Hill	Woodside Creek	Dt	
S36/f647		M	Mead Hill	Woodside Creek	Mh	
P31/f16	18/2	M	Mead Hill	Mt.Alexander	Dt	
P31/f15	18/3	M	Mead Hill	Mt.Alexander	Mh	
S36/f633		M	Mead Hill	Woodside Creek	Mh	
P30/f38		M	Mead Hill	Woodside Creek	Mh(upper)	Upper slope
P30/f34		M	Mead Hill	Woodside Creek	Mh(upper)	Upper slope
P30/f32		M	Mead Hill	Woodside Creek	Mh(upper)	Upper slope
P30/f30		M	Mead Hill	Woodside Creek	Mh(upper)	Upper slope
P30/f29		M	Mead Hill	Woodside Creek	Mh(upper)	Upper slope
P30/f27		M	Mead Hill	Woodside Creek	Dt(lower-mid)	Outer shelf
P30/f26		M	Mead Hill	Woodside Creek	Dt(lower-mid)	Outer shelf
P30/f25		M	Mead Hill	Woodside Creek	Dt(lower-mid)	Outer shelf
P30/f22		M	Mead Hill	Woodside Creek	Dt(lower-mid)	Outer shelf
P30/f19		M	Mead Hill	Woodside Creek	Dt(lower-mid)	Outer shelf
P30/f15		M	Mead Hill	Woodside Creek	Dt(lower-mid)	Outer shelf
P30/f13		M	Mead Hill	Woodside Creek	Dt(lower-mid)	Outer shelf
P29/f169		M	Mead Hill	Chancet Rocks	Mh(upper)	Mid to upper bathyal
P29/f219		M	Mead Hill	Chancet Rocks	Mh(upper)	Mid to upper bathyal
P29/f220		M	Mead Hill	Chancet Rocks	Mh(upper)	Mid to upper bathyal
P29/f221		M	Mead Hill	Chancet Rocks	Dt(lower-mid)	
P29/f222		M	Mead Hill	Chancet Rocks	Dt(lower-mid)	
P29/f223		M	Mead Hill	Chancet Rocks	Dt(lower-mid)	
P29/f184		M	Mead Hill	Needles Point	Mh(upper)	
P29/f185		M	Mead Hill	Needles Point	Mh(upper)	
P29/f186		M	Mead Hill	Needles Point	Dt	
P29/f208		M	Mead Hill	Needles Point	Dt	
P29/f209		M	Mead Hill	Needles Point	Dt	

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NZ FRF No.	Field No.		Formation	Location	Stage	Environment
P30/f266		M	Mead Hill	Woodside Creek	Dt	
S36/f632		M	Mead Hill	Woodside Creek	Mh	
S36/f646		M	Mead Hill	Woodside Creek	Mh	
P31/f14	18/4	M	Mead Hill	Mt.Alexander	Mh	Inner shelf
P30/f270		M	Mead Hill	Woodside Creek	Dt	
P31/f43	19/7	T	Mead Hill	Mororimu Stm	Mh	Outer shelf
P31/f45	19/12	T	Mead Hill	Mororimu Stm	Dw(approx)	
O30/f141	42/13	T	Mead Hill	Dart Stream	Dw(lower)	
O30/f139	43/16	T*	Mead Hill	Muzzle Stream	Dt-Dw	
O30/f140	42/14	T*	Mead Hill	Dart Stream	Dw	
P31/f41	25/11	T*	Mead Hill	Puhi Puhi River	Mh	
S42/f654		T*	Mead Hill	Bluff River	ND	
S42/f655		T*	Mead Hill	Bluff River	ND	
O31/f176	4/4	T*	Mead Hill	Kaikoura Pnsla	Dt(lower)	Mid shelf
S42/f674		T*	Mead Hill	Muzzle Stream	ND	
P31/f32	20/3	T*	Mead Hill	Puhi Puhi River	Mh	
O30/f143	52/4	T*	Mead Hill	Bluff River	Mh	Inner shelf
O30/f2			Teredo Limestone	Limestone Hill	ND	
O31/f35			Teredo Limestone	Seymour Stream	#	
S42/f675			Teredo Limestone	Muzzle Stream	ND	
O30/f11			Teredo Limestone	Limestone Hill	Dw-Ab	
S55/f214			Teredo Limestone	Conway River Mth	Dm	
S55/f780A			Teredo Limestone	Conway River Mth	Dw-Dm	
O31/f233	123/4		Teredo Limestone	The Fell	Dh	
S55/f780			Teredo Limestone	Conway River Mth	Dw-Dm	
O31/f84			Teredo Limestone	Seymour Stream	D-A	
O31/f83			Teredo Limestone	Seymour Stream	D-A	

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NZ FRF No.	Field No.		Formation	Location	Stage	Environment
S56/f550			Teredo Limestone	Haumuri Bluff	Dt(upper)-Dw	
032/f9804A			Teredo Limestone	Haumuri Bluff	Dw	
S42/f656			Teredo Limestone	Bluff River	ND	
S36/f783			Teredo Limestone	Needles Point	Dw	
032/f26			Teredo Limestone	Conway River Mth	Dw(mid)-Dm(mid)	
S55/f781		T	Teredo Limestone	Conway River Mth	Dm	Outer shelf to bathyal
030/f133	51/3	T	Teredo Limestone	Gentle Annie Stm	Dw	
030/f63	128/1	T	Teredo Limestone	Limestone Hill	#	
031/f211	125/1	T	Teredo Limestone	Wallow Creek	Tertiary	
S55/f781A		T	Teredo Limestone	Conway River Mth	Dm	
S41/f569		T	Teredo Limestone	Seymour Stream	D	
P30/f97		B	Lower Limestone (UCM)	Mead Stream	Dw	
P30/f94		B	Lower Limestone (UCM)	Mead Stream	ND	
P30/f98		B	Lower Limestone (UCM)	Mead Stream	Dw	
P30/f95		B	Lower Limestone (UCM)	Mead Stream	ND	
P30/f96		B	Lower Limestone (UCM)	Mead Stream	D	
P30/f99		B	Lower Limestone (UCM)	Mead Stream	Dw	
P30/f289	30/21	B	Lower Limestone	Mead Stream	Dt?-Dw	
P31/f34	20/10	M	Lower Limestone	Puhi Puhi River	Dw	
S42/f671		T	Lower Limestone	Dead Horse Gully	ND	
030/f148	50/9	T	Lower Limestone	Bluff Stm (upper)	Dw-Dm(lower)	
P30/f290	30/24	T	Lower Limestone	Mead Stream	Dm-Dh	
030/f101	42/17	T	Lower Limestone	Dart Stream	Dw(lower)	Outer shelf to bathyal
031/f175	4/6	B!	Lower Marl	Kaikoura Pnsla	Dm(upper)-Dh	Bathyal, oceanic
031/f241	122/4	B!	Lower Marl	Seymour Stream	Dh	
030/f64	128/2	B!	Lower Marl	Limestone Hill	#	

APPENDIX I: Micropaleontological Age & Environmental Determinations

NZ FRF No.	Field No.		Formation	Location	Stage	Environment
O31/f212	125/2	B!	Lower Marl	Wallow Creek	Dm(lower)	Bathyal
O30/f65	128/3	B!	Lower Marl	Limestone Hill	#	
S36/f782			Lower Marl?	Needles Point	Dm-Dh	
S36/f850			Lower Marl	Isolation Creek	Dm-Dh	
S36/f867			Lower Marl	Ben More	Dm-Dh	
S36/f965			Lower Marl	Woodside Creek	Dh	
S36/f847			Lower Marl	Isolation Creek	Dm-Dh	
S36/f867			Lower Marl	Woodside Creek	Dm-Dh	
S36/f628			Lower Marl	Woodside Creek	Dm-Dh(lower)	
S36/f844			Lower Marl	Ure River	Dm-Dh	
S36/f630			Lower Marl	Woodside Creek	Dm(upper)-Dh(lower)	
O31/f34		B	Lower Marl	Seymour Stream	#	
S36/f818		B	Lower Marl	Blue Mtn Stm	Dm-Dh	
O31/f85		B	Lower Marl	Seymour Stream	Dh	
O30/f147	43/18	B	Lower Marl	Muzzle Stream	Dw	
O31/f87		B	Lower Marl	Seymour Stream	Dh	
S36/f831		B	Lower Marl	Woodside Creek	Dm-Dh	
P30/f175		B	Lower Marl	Woodside Creek	Dw	
O31/f146		B	Lower Marl	The Fell	Dt?-Dm?	
P30/f288	30/25	B	Lower Marl	Mead Stream	Dm	
O30/f146	50/11	B	Lower Marl	Bluff Stm (upper)	Dw(upper)-Dm(lower)	
O31/f59		B	Lower Marl	Seymour Stream	Dm-Dh	
P30/f105		B	Lower Marl	Mead Stream	#	
P29/f243	112/3	B	Lower Marl	Isolation Creek	#	
O30/f52	10/7	B	Lower Marl	Dart Stream	Dt(upper)-Dw(lower)	Bathyal, oceanic
O31/f86		B	Lower Marl	Seymour Stream	Dh	
O30/f97	41/1	B	Lower Marl	Whisky Stream	#	
P30/f1		M	Lower Marl	Woodside Creek	Dw-Dm	

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NZ FRF No.	Field No.		Formation	Location	Stage	Environment
P31/f17	18/1	T	Lower Marl	Mt.Alexander	Dw-Dh	
P30/f287	30/33	T	Lower Marl	Mead Stream	Dh	
P29/f244	112/2	T	Lower Marl	Isolation Creek	#	
S36/f819		T	Lower Marl	Blue Mtn Stm	Dm-Dh	
030/f98	41/4	T	Lower Marl	Whisky Stream	#	
030/f66	128/4	T	Lower Marl	Limestone Hill	#	
P30/f176		T	Lower Marl	Woodside Creek	Dm	
030/f144	42/18	T	Lower Marl	Dart Stream	Dh	Bathyal
030/f145	50/16	T	Lower Marl	Bluff Stm (upper)	Dm-Dh	
S42/f522		T	Lower Marl	Limestone Hill	Dh	
S36/f830		T*	Lower Marl	Woodside Creek	Dm-Dh	
S36/f625		B	Woodside Formation	Woodside Creek	Dm(late)-Dh(early)	
S36/f829			Woodside Formation	Woodside Creek	Dw(upper)-Dh	
P30/f2			Woodside Formation	Woodside Creek	Dm-Dh	
S56/f512		B!	Middle Limestone	Haumuri Bluff	Dm	
032/f32		B!	Middle Limestone	Conway River Mth	Dm-Dh	Outer shelf to bathyal
S55/f782A		B	Middle Limestone	Conway River Mth	Dm	
S55/f782		B	Middle Limestone	Conway River Mth	Dm	
030/f53	10/8	B	Middle Limestone	Dart Stream	Dm(upper)-Dh	Outer shelf to bathyal
030/f99	41/5	B	Middle Limestone	Whisky Stream	Dm-Dh	Bathyal
031/f225	120/1	B	Middle Limestone	Seymour Stream	#	
030/f67	128/5	B	Middle Limestone	Limestone Hill	#	
030/f8		B	Middle Limestone	Limestone Hill	Ab-Ar	
032/f25		M	Middle Limestone	Oaro	Ab	Bathyal (Dm-Dh rwkd)
S36/f823		M	Middle Limestone	Ure River	Ab	
030/f135	42/19	M	Middle Limestone	Dart Stream	Dh	Bathyal

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NZ FRF No.	Field No.		Formation	Location	Stage	Environment
S36/f821		T	Middle Limestone	Ure River	Dp-Ab	
S55/f224		T	Middle Limestone	Conway River Mth	Ab	
S55/f210		T	Middle Limestone	Conway River Mth	Ab	
030/f100	41/6	T	Middle Limestone	Whisky Stream	Ab	Bathyal
S36/f846		T	Middle Limestone	Isolation Creek	Dp-Ab	
S36/f817		T	Middle Limestone	Blue Mtn Stm	Dp-Ab	
S55/f211		T	Middle Limestone	Conway River Mth	Ab	
032/f39	3/2	T	Middle Limestone	Oaro	Ab	Bathyal, oceanic
030/f134	42/9		Middle Limestone (FG)	Dart Stream	Dp-?Ab(lower)	
030/f126	50/17	B	Upper Marl (FG)	Bluff Stm (upper)	Ab	
030/f125	51/2	M	Upper Marl (FG)	Gentle Annie Stm	Ab-Ar	
S55/f9			Upper Marl	Conway River Mth	Ak-Ar	
031/f60			Upper Marl	Seymour Stream	Ab	
S36/f866			Upper Marl	Deep Creek	Ab	
032/f24			Upper Marl	Oaro	Ak	
S36/f814			Upper Marl	Blue Mtn Stm	Ab	
S36/f839			Upper Marl	Woodside Creek	Ab	
030/f39			Upper Marl	Bluff Stm (upper)	Ar	
032/f27			Upper Marl	Conway River Mth	Ab	Outer shelf to bathyal
S55/f215		B	Upper Marl	Conway River Mth	Ab	
030/f45		B	Upper Marl	Muzzle Stream	Ab	
030/f132	42/6	B	Upper Marl	Dart Stream	Ab	
031/f239	121/1	B	Upper Marl	Seymour Stream	Ab-Ar	
P30/f285	30/36	B	Upper Marl	Mead Stream	Ab	
032/f33	15/8	B	Upper Marl	Haumuri Bluff	Ab	Outer shelf to bathyal

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NZ FRF No.	Field No.		Formation	Location	Stage	Environment
P29/f245	112/1	B	Upper Marl	Isolation Creek	#	
P30/f182		B	Upper Marl	Mead Stream	Ab	
O31/f185	7/4	B	Upper Marl	Cribb Creek	Ak	Outer shelf to bathyal
O30/f131	127/2	B	Upper Marl	Grass Seed Stream	Ab(upper)	
P30/f177		B	Upper Marl	Woodside Creek	Ab	
P30/f106		B	Upper Marl	Mead Stream	#	
S36/f813		B?	Upper Marl	Blue Mtn Stm	Ab	
P30/f107		M	Upper Marl	Mead Stream	#	
O31/f153		M	Upper Marl	Kaikoura Pnsla	#	
S55/f216		M	Upper Marl	Conway River Mth	Ab	
O32/f40	3/3	M	Upper Marl	Oaro	Ab(upper)	
O31/f145		M	Upper Marl	The Fell	Dp	
O32/f34	15/7	M	Upper Marl	Haumuri Bluff	Ab(prob upper)	
S36/f822		T	Upper Marl	Ure River	Ab	
P30/f284	30/41	T*	Upper Marl	Mead Stream	Ar	
O30/f95	40/27	T*	Upper Marl	Branch Stm (sth)	#	
O30/f127	128/7	T*	Upper Marl	Limestone Hill	Ab	
O31/f240	121/2	T*	Upper Marl	Seymour Stream	Ab-Ar	
P30/f110		T*	Upper Marl	Mead Stream	#	
O32/f35	15/6	T*	Upper Marl	Haumuri Bluff	Ab(lower-mid)-rwkd	Outer shelf to bathyal
O30/f129	50/20	T*	Upper Marl	Bluff Stm (upper)	Ar	
O31/f183	1/5	T*	Upper Marl	Kaikoura Pnsla	Ak	Outer shelf to bathyal
O31/f151		T*	Upper Marl	Kaikoura Pnsla	Ab	
O30/f92	40/21	T*	Upper Marl	Branch Stm (mid)	Ab	
O31/f156		T*	Upper Marl	Kaikoura Pnsla	#	
O32/f28		T*	Upper Marl	Oaro	Ar	Outer shelf to bathyal
O30/f130	100/1	T*	Upper Marl	Tirohanga Stm	Ab-Ar	
O31/f74		T*	Upper Marl	Seymour Stream	Ak(lower)	

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NZ FRF No.	Field No.		Formation	Location	Stage	Environment
031/f186	7/3	T*	Upper Marl	Cribb Creek	Ak-Ar	Oceanic
032/f31		T*	Upper Marl	Oaro	Ar(upper)	Outer shelf to bathyal
P30/f108		T*	Upper Marl	Mead Stream	#	
P30/f109		T*	Upper Marl	Mead Stream	#	
P29/f242	111/1	T*	Upper Marl	Ure River	#	
030/f128	42/4	T*	Upper Marl	Dart Stream	Ab(upper)-Ak(lower)	
S36/f838			Upper Marl (RM)	Woodside Creek	Ab	
S36/f816		B	Upper Marl (RM)	Blue Mtn Stm	Dp-Ab	
P30/f222			Upper Marl (GV)	Ben More Stm	Ab(upper)	
P30/f224			Upper Marl (GV)	Ben More Stm	Ab(upper)	
030/f68	127/2	B	Upper Marl (GV)	Grass Seed Stream	Ab	
030/f124	50/26	B	Upper Marl (GV)	Bluff Stm (lower)	Ab-Ak	
S42/f516		B	Upper Marl (GV)	Grass Seed Stream	Ab(upper)	
030/f123	127/1	M	Upper Marl (GV)	Grass Seed Stream	Ab(upper)	
S36/f812			Grass Seed Volcanics	Blue Mtn Stm	Ab	
S36/f828			Grass Seed Volcanics	Ure River	A	
S36/f827			Grass Seed Volcanics	Ure River	Dw-Ar	
P29/f240	109/3		Grass Seed Volcanics	Ure River	#	
P29/f241	110/3		Grass Seed Volcanics	Blue Mountain Stm	#	
S42/f515		M	Grass Seed Volcanics	Grass Seed Stream	Ab	
S42/f514		M	Grass Seed Volcanics	Grass Seed Stream	Ab	
030/f9		T*	Grass Seed Volcanics	Grass Seed Stream	Ab	
031/f210	123/6	B	Cookson Volcanics (PCB)	The Fell	Lwh(upper)-Ld	Bathyal
030/f7		B	Cookson Volcanics	Limestone Hill	Lwh-Ld	
031/f242	121/3	B	Cookson Volcanics	Seymour Stream	Lwh	
030/f149	128/8	B	Cookson Volcanics	Limestone Hill	Ar (?rwkd)	

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NZ FRF No.	Field No.		Formation	Location	Stage	Environment
030/f96	128/11	M	Cookson Volcanics	Limestone Hill	#	
031/f61		T	Cookson Volcanics	Seymour Stream	Lwh	
031/f184	1/8	B	Weka Pass Stone (PCB)	Kaikoura Pnsla	ND	
032/f23		B	Weka Pass Stone (PCB)	Oaro	Ld(upper)-Lw(lower)	
032/f29		B	Weka Pass Stone (PCB)	Oaro	Lw(lower)	Outer shelf
030/f96	40/28	B	Weka Pass Stone	Branch Stm (sth)	#	
030/f93	40/22	B	Weka Pass Stone	Branch Stm (mid)	Ak-Sc	
S55/f228		B	Weka Pass Stone	Oaro	Ld?-Lw	
030/f121	42/5	B	Weka Pass Stone	Dart Stream	Lw	
032/f22		B	Weka Pass Stone	Oaro	Lw(lower)	
032/f30		B	Weka Pass Stone	Oaro	Lw(lower)	Outer shelf
032/f36	15/2	B	Weka Pass Stone	Haumuri Bluff	Lw(lower)	Outer shelf or bathyal
030/f69	50/21	B	Weka Pass Stone	Bluff Stm (upper)	ND	
031/f155		B	Weka Pass Stone	Kaikoura Pnsla	#	
032/f37	15/3	T	Weka Pass Stone	Haumuri Bluff	Lw(lower)	Outer shelf or bathyal
031/f132		T	Weka Pass Stone	Kaikoura Pnsla	Ld-Sc	
032/f43	3/7	B	Waima Siltstone	Oaro	Lw(lower)	Outer shelf
031/f44		B	Waima Siltstone	The Fell	#	
031/f119		B	Waima Siltstone	Cribb Creek	Lw-Po	Bathyal
030/f122	100/2	B	Waima Siltstone	Tirohanga Stm	Lw	
S36/f825		B	Waima Siltstone	Ure River	Lwh-Ld	
032/f42	3/6	B	Waima Siltstone	Oaro	Lw(lower)	Mid to outer shelf
031/f133		B	Waima Siltstone	Kaikoura Pnsla	Lw-Po	
031/f154		B	Waima Siltstone	Kaikoura Pnsla	#	
030/f46		B	Waima Siltstone	Muzzle Stream	Lw-Po	
S36/f826		M	Waima Siltstone	Ure River	Lw	

APPENDIX II: GEOCHEMISTRY

Methods

Representative samples from each Formation were selected for geochemical analysis. Wherever possible, a limestone (L) and a marl (M) pair were analysed at each sampling horizon.

Whole rock samples were analysed for major and minor elements (Tables II.a,b) using a Philips PW 1400 Energy Dispersive XRF Spectrometer. All elements and oxides, except Sr and CaO, showed an inversely proportional ratio to wt%$CaCO_3$. Insoluble residue values were recalculated on a carbonate-free basis (Tables II.c,d).

$CaCO_3$ totals were calculated using the method outlined in Lawrence (1982). Pre-weighed, air-dried powdered samples were dissolved in c.10% HCl. Solutions were washed through pre-weighed filter papers. The weight of insoluble residue was calculated after drying, and subtracted from original sample weight to provide the raw weight of $CaCO_3$. This weight was expressed as a percentage of the original sample weight to give the wt%$CaCO_3$.

Insoluble residue mineral composition was determined qualitatively using a Philips X-Ray Diffractometer (Figs II.a-i). Using the calibration curves for wt% Illite / wt% Smectite (I/S), shown in Fig 4.9 of Fergusson (1985), semi-quantitative estimates were made on samples with a simple, 3-component (quartz, illite, smectite) mineralogy (Tables II.e,f). From analyses in Brownlow (1979), it can be shown that illite, smectite, kaolinite, and clinoptilolite (I+S+K+Z) all contain approximately 50% SiO_2.

The weight % quartz, illite and smectite were then determined using the follwing equations:

$$SiO_2 = 0.5C + Q \quad \ldots\ldots 1$$

$$Q + C = 100 \quad \ldots\ldots 2$$

where SiO_2 = wt%SiO_2

and C = wt% Illite + wt% Smectite

and Q = wt% Quartz

Combining 1 & 2

$$\Rightarrow \quad SiO_2 - 0.5C = 100 - C$$

$$\Rightarrow \quad 0.5C = 100 - SiO_2$$

$$\Rightarrow \quad \underline{C = 2(100 - SiO_2)} \quad \ldots\ldots 3$$

Combining 2 & 3

$$\Rightarrow \quad \underline{Q = 100 - C} \quad \ldots\ldots 4$$

$$\text{Weight\% Illite} = (\text{wt\% Illite} / \text{wt \% Smectite}) \times C \quad \ldots 5$$

$$\text{Weight\% Smectite} = C - \text{wt\% Illite} \quad \ldots\ldots 6$$

TABLE IIa: Whole Rock XRF (Major Element) Data.

SAMPLE NO.	$CaCO_3$ wt%	TOTAL	LOI	MgO	Na_2O	SiO_2	Al_2O_3	P_2O_5	Fe_2O_3	MnO	TiO_2	CaO	K_2O
WEKA PASS STONE													
42/5	45.56	98.62	21.02	1.05	1.19	38.28	7.26	.19	2.87	.03	.37	25.21	1.15
30/42	80.13	98.53	34.89	.24	.20	15.61	1.92	.23	.82	.02	.12	44.18	.30
1/7	91.76	98.28	39.45	.39	.43	5.65	.93	.78	.90	.04	.03	49.37	.31
Mean	72.48			.56	.60	19.85	3.37	.40	1.53	.03	.17	39.59	.59
UPPER MARL													
50/20 M	69.92	99.88	33.45	.91	.22	19.10	4.52	.30	1.77	.02	.17	38.71	.71
42/4 M	70.58	99.50	32.62	.67	.21	21.47	3.83	.11	1.29	.03	.14	38.61	.52
30/40 M	65.99	98.79	30.57	.64	.25	24.29	4.56	.08	1.36	.01	.17	36.26	.60
30/40 L	77.86	99.43	36.15	.37	.18	15.29	2.94	.08	.91	.02	.11	43.00	.38
104/17 M	52.41	100.59	24.02	.87	.40	36.22	6.60	.11	1.85	.05	.23	29.35	.89
104/15 M	74.00	99.20	34.63	.52	.14	15.33	4.88	.11	1.85	.04	.17	40.82	.71
127/1 M	48.57	100.63	23.43	2.01	.41	33.36	7.95	.15	3.05	.08	.35	27.11	2.73
50/18 M	66.92	99.03	31.20	.45	.27	24.73	2.98	.08	.99	.02	.11	37.66	.54
50/17 M	66.74	100.02	31.57	.51	.26	25.96	3.37	.06	1.03	.01	.13	36.58	.54
50/17 L	83.34	100.20	38.33	.22	.16	13.72	1.25	.06	.43	.03	.03	45.78	.19
42/6 M	83.52	100.84	38.72	.48	.15	12.82	2.59	.08	.66	.04	.09	44.89	.32
30/37 M	59.31	98.21	26.73	.76	.34	30.41	6.30	.11	1.91	.02	.25	30.58	.80
30/37 L	72.65	100.57	33.22	.39	.20	22.22	2.87	.08	.84	.01	.10	40.31	.33
15/8 M	78.98	98.32	35.97	.54	.45	13.74	3.05	.09	.77	.02	.11	42.94	.64
15/8 L	84.10	99.23	38.05	.34	.36	11.45	1.84	.07	.49	.01	.06	46.18	.38
104/16 M	54.49	99.49	26.00	.70	.51	33.52	5.65	.06	1.29	.07	.23	30.56	.90
104/16 L	66.28	99.13	30.82	.61	.26	23.37	4.41	.06	1.00	.09	.16	37.75	.60
Mean M	65.95			.76	.30	24.25	4.69	.11	1.49	.03	.18	36.17	.83
Mean L	76.85			.39	.23	17.21	2.66	.07	.73	.03	.09	42.60	.38
FELLS GREENSAND													
50/18	37.66	98.69	16.53	.29	.40	56.57	1.98	.03	1.52	.01	.07	20.54	.75
42/7	36.71	99.15	16.42	.27	.71	67.45	3.16	.05	1.28	.01	.11	19.92	.90
105/3	31.26	100.38	14.45	.32	.95	59.86	4.05	.02	1.57	.03	.19	17.60	1.34
104/17	24.00	98.87	11.43	.47	.16	67.45	2.25	.05	2.99	.02	.04	12.63	1.38
104/16	48.00	99.63	23.11	.35	.91	40.65	4.12	.03	.99	.06	.17	28.30	.94
Mean	35.53			.34	.63	58.40	3.11	.04	1.67	.03	.12	19.80	1.06

TABLE IIa: Whole Rock XRF (Major Element) Data.

SAMPLE NO.	CaCO3 wt%	TOTAL	LOI	MgO	Na2O	SiO2	Al2O3	P2O5	Fe2O3	MnO	TiO2	CaO	K2O
MIDDLE LIMESTONE													
50/26 M	78.50	100.12	36.60	.63	.09	12.86	3.05	.09	1.19	.05	.10	44.97	.49
50/26 L	84.03	99.10	37.87	.35	.09	12.00	1.66	.09	.60	.04	.05	46.10	.25
42/7 M	86.07	98.70	37.05	.11	.11	14.35	.61	.04	.22	.03	.01	46.11	.06
42/7 L	87.70	100.21	38.73	.12	.17	12.94	.73	.04	.36	.04	.01	47.00	.07
32/1 L	94.18	99.58	41.53	.10	.08	4.83	.49	.05	.16	.04	0.00	52.27	.03
30/35 M	79.08	98.49	35.87	.64	.13	12.02	4.03	.29	.89	.05	.13	43.88	.56
30/35 L	91.13	99.35	40.28	.08	.14	7.85	.70	.05	.20	.03	.01	49.96	.05
20/15 L	84.39	100.01	35.05	.12	.08	15.25	.59	.06	.19	.03	0.00	48.60	.04
Mean M	81.22			.46	.11	13.08	2.56	.14	.77	.04	.08	44.99	.37
Mean L	88.29			.15	.11	10.57	.83	.06	.30	.04	.01	48.79	.09
LOWER MARL													
50/16 M	73.12	100.50	35.62	.60	.22	15.74	3.67	.13	.97	.05	.13	42.89	.48
50/16 L	75.08	99.74	33.85	.36	.11	16.69	2.45	.08	.60	.03	.09	45.14	.34
30/32 M	72.61	100.20	34.73	.61	.15	18.74	4.05	.10	1.25	.06	.14	39.90	.47
30/32 L	75.41	98.18	33.77	.26	.10	19.98	1.89	.06	.70	.06	.05	41.12	.19
128/4 M	62.01	100.56	29.00	.98	.17	26.59	6.48	.17	1.80	.02	.24	34.32	.79
30/30 M	59.89	98.72	27.02	.81	.15	29.60	6.28	.11	1.83	.05	.23	31.80	.84
30/30 L	70.89	98.25	32.40	.35	.12	22.98	2.18	.08	.71	.08	.06	39.05	.24
128/3 M	42.02	99.45	21.45	1.33	.23	40.41	9.09	.13	2.22	.02	.36	23.10	1.11
128/3 L	67.76	99.29	31.58	.45	.16	25.79	2.69	.14	.89	.05	.10	37.11	.33
50/11 M	64.18	98.81	30.52	.92	.24	23.64	5.15	.20	1.24	.06	.19	35.99	.66
50/11 L	69.46	99.27	31.38	.21	.17	27.38	1.49	.08	.39	.06	.04	37.84	.23
30/27 M	58.50	99.01	27.15	.93	.19	30.36	5.81	.15	1.55	.04	.21	31.80	.82
30/27 L	72.24	99.03	33.36	.32	.40	20.35	1.95	.09	.56	.09	.06	41.59	.26
Mean M	61.76			.88	.19	26.44	5.79	.14	1.55	.04	.21	34.26	.74
Mean L	71.81			.33	.17	22.20	2.11	.09	.64	.06	.07	40.31	.27
LOWER LIMESTONE													
20/5 L	46.72	98.76	20.27	.38	.56	47.36	2.25	.41	1.00	.05	.08	25.79	.61
104/5 L	79.90	98.89	36.07	.25	.26	14.91	1.50	.19	.76	.11	.04	44.60	.20
30/22 M	77.90	98.01	35.49	.70	.18	14.22	2.66	.28	1.14	.08	.10	42.70	.46
30/22 L	77.42	99.70	35.77	.36	.10	18.38	1.69	.16	.56	.07	.05	42.31	.25

TABLE IIa: Whole Rock XRF (Major Element) Data.

SAMPLE NO.	CaCO3 wt%	TOTAL	LOI	MgO	Na2O	SiO2	Al2O3	P2O5	Fe2O3	MnO	TiO2	CaO	K2O
TEREDO LIMESTONE													
5/1	75.00	98.75	32.27	.38	.76	23.42	1.96	.17	.85	.03	.05	38.17	.69
50/24	23.16	98.35	10.43	.37	1.74	61.94	6.72	.17	1.15	.05	.46	13.24	2.08
MEAD HILL FORMATION													
42/12 M	26.03	99.73	13.50	3.98	.34	50.88	9.71	.29	2.84	.03	.37	15.60	2.19
42/12 L	45.45	98.71	21.12	1.03	.17	47.63	2.37	.09	.68	.02	.08	25.05	.47
4/3 M	27.42	98.13	12.93	.82	1.12	59.55	6.19	.13	1.71	.03	.25	14.42	.98
4/3 L	17.44	99.88	8.55	.25	.37	79.58	1.77	.04	.40	.03	.07	8.51	.31
30/14 M	53.00	100.61	24.32	1.29	.18	40.44	3.36	.13	.93	.07	.13	28.93	.83
30/14 L	29.88	100.10	14.12	1.48	.23	64.32	2.82	.13	.72	.04	.10	15.45	.69
20/4 L	18.80	100.07	10.02	.49	.52	73.67	3.42	.06	.80	.02	.13	10.33	.61
20/2 L	25.58	99.80	12.55	.32	.40	68.98	2.36	.05	.70	.03	.10	13.89	.42
104/1 M	41.82	99.61	20.98	2.73	.33	44.28	4.36	.15	2.17	.17	.18	23.22	1.04
104/1 L	46.68	99.21	20.62	1.48	.21	48.25	2.01	.08	.93	.17	.07	24.97	.42
Mean M	37.07			2.21	.49	48.79	5.91	.18	1.91	.08	.23	20.54	1.26
Mean L	30.64			.84	.32	63.74	2.46	.08	.71	.05	.09	16.37	.49
CLAVERLEY SANDSTONE													
50/3	20.41	99.57	10.53	.54	.88	68.82	4.45	.22	1.72	.03	.16	11.22	1.00
43/11	4.92	99.71	2.02	.45	.90	86.49	4.42	.99	1.11	.01	.16	2.36	.80
10/3	4.68	99.25	2.10	.57	2.37	82.00	7.29	.06	1.27	.03	.22	2.20	1.14
Mean (43/11,10/3)	4.80			.51	1.64	84.25	5.86	.53	1.19	.02	.19	2.28	.97
WOOLSHED FORMATION													
40/13	4.50	98.18	4.82	1.76	2.24	69.65	13.00	.07	3.54	.03	.56	.18	2.33
112/6	2.27	98.37	1.68	.80	.70	87.13	5.11	.04	1.44	.02	.23	.24	.97
10/4	9.92	99.40	2.28	1.41	2.74	73.74	12.80	.09	3.37	.03	.53	.41	2.00
1/4	7.26	99.08	3.57	1.33	1.59	79.40	8.25	.10	2.69	.03	.38	.28	1.46
Mean	5.99			1.33	1.82	77.48	9.79	.08	2.76	.03	.43	.28	1.69

TABLE IIb: Whole Rock XRF (Trace Element) Data.

SAMPLE NO.	Sr ppm	Rb	Y	Pb	Th	Ga	Nb	Ba	V	Cr	Nd	Ce	Zn	Ni	La
WEKA PASS STONE															
42/5	647	50	13	7	3	8	3	227	67	60	12	30	54	25	12
30/42	898	13	14	5	0	2	2	131	25	21	7	16	28	9	16
1/7	837	9	49	4	0	1	2	2	29	21	12	17	27	24	27
Mean	794	24	25	5	1	4	2	120	40	34	10	21	36	19	18
UPPER MARL															
50/20 M							2	143	68	23	2	23	54	25	14
42/4 M	234	33	6	8	1	3	2	122	40	17	0	15	36	14	9
30/40 M	861	27	9	7	2	6	3	976	39	19	4	15	47	19	10
30/40 L	571	37	13	6	1	3	0	837	31	13	0	11	26	12	10
104/17 M	937	35	17	8	2	6	5	1182	59	32	9	24	57	31	12
104/15 M	731	29	6	8	1	2	0	1826	33	14	2	26	28	12	12
127/1 M	407	60	11	10	4	9	5	125	68	44	10	32	69	46	12
50/18 M	856	16	10	6	2	3	2	1578	29	15	2	23	28	10	14
50/17 M							0	1070	33	12	0	16	37	19	10
50/17 L							0	275	20	5	0	7	16	6	8
42/6 M							0	738	23	8	0	20	21	20	13
30/37 M	588	30	8	8	3	3	3	794	54	26	0	19	46	24	11
30/37 L	504	41	9	7	3	5	0	1190	33	12	3	15	19	9	10
15/8 M	1010	19	12	44	1	1	2	1758	32	11	3	17	27	12	8
15/8 L	996	11	8	6	0	0	0	1525	23	5	0	17	19	9	5
104/16 M	840	9	9	4	0	1	2	1376	37	23	0	31	26	19	8
104/16 L	744	24	9	6	0	3	2	1492	29	17	8	18	20	15	9
Mean M	718	29	10	11	2	4	2	974	43	20	3	22	40	21	11
Mean L	704	28	10	6	1	3	0	1064	27	10	2	14	20	10	8
FELLS GREENSAND															
50/18	477	25	4	6	0	1	0	1597	27	22	0	9	20	3	2
42/7							1	1085	25	18	0	8	29	21	4
105/3	213	43	4	7	2	3	1	504	29	37	0	8	21	5	1
104/17	152	46	4	6	1	2	0	221	38	58	0	12	25	2	3
104/16							0	600	29	18	0	8	0	9	5
Mean	230	23	3	4	1	1	0	801	30	31	0	9	19	8	3

TABLE IIb: Whole Rock XRF (Trace Element) Data.

SAMPLE NO.	Sr ppm	Rb	Y	Pb	Th	Ga	Nb	Ba	V	Cr	Nd	Ce	Zn	Ni	La
MIDDLE LIMESTONE															
50/26 M	920	19	11	5	1	2	2	1192	23	12	0	20	25	15	10
50/26 L	986	10	9	5	0	0	2	842	17	3	0	18	14	38	8
42/7 M	793	22	10	5	0	1	2	572	12	2	0	8	9	6	5
42/7 L	676	48	12	8	2	7	0	173	15	3	0	7	7	3	7
32/1 L	1105	1	7	4	0	0	0	1646	11	0	0	5	4	6	7
30/35 M	1106	29	33	9	5	6	2	410	54	20	23	35	48	35	7
30/35 L	1176	1	8	7	0	1	0	72	14	0	0	10	7	5	9
20/15 L	852	1	5	5	0	0	0	809	11	0	0	13	8	2	6
Mean M	940	23	18	6	2	3	2	725	30	11	8	21	27	19	7
Mean L	959	12	8	6	0	2	0	708	14	1	0	11	8	11	7
LOWER MARL															
50/16 M	898	43	12	11	3	6	2	10073	14	9	0	18	24	11	8
50/16 L	945	4	6	3	0	0	2	20212	0	2	0	13	14	4	6
30/32 M	508	52	14	13	6	10	2	1322	27	16	3	20	25	10	11
30/32 L	554	17	13	7	1	1	0	1695	16	6	0	16	18	4	8
128/4 M	859	32	11	7	2	4	2	2226	50	21	6	28	42	21	15
30/30 M	511	31	27	8	2	5	3	2068	37	23	1	27	36	24	13
30/30 L	695	13	12	4	0	0	0	2342	17	8	0	21	13	3	11
128/3 M	1012	21	9	5	0	2	6	758	73	35	13	31	49	22	15
128/3 L	983	17	10	6	0	1	1	350	23	11	4	21	18	8	13
50/11 M	1154	3	5	4	0	0	2	2070	36	21	10	41	38	41	21
50/11 L	792	36	16	10	2	5	1	2912	11	5	0	14	10	9	6
30/27 M	1055	21	11	5	0	0	3	2509	39	24	7	23	42	39	14
30/27 L	731	29	6	8	1	2	0	1826	33	14	2	26	28	12	12
Mean M	857	29	13	8	2	4	3	3004	39	21	6	27	37	24	14
Mean L	783	19	11	6	1	2	1	4890	17	8	1	19	17	7	9
LOWER LIMESTONE															
20/5 L	459	24	47	7	0	3	2	506	37	62	24	33	28	8	39
104/5 L	430	9	22	6	0	2	2	1019	15	8	11	23	26	14	19
30/22 M	713	19	29	8	3	3	2	1723	27	14	9	33	55	67	21
30/22 L	744	10	18	8	0	0	2	2039	19	8	0	21	32	16	14

TABLE IIb: Whole Rock XRF (Trace Element) Data.

SAMPLE NO.	Sr ppm	Rb	Y	Pb	Th	Ga	Nb	Ba	V	Cr	Nd	Ce	Zn	Ni	La
TEREDO LIMESTONE															
5/1	383	16	10	6	0	0	0	91	18	11	6	14	16	8	6
50/24	408	36	13	7	3	7	9	417	68	58	15	36	44	61	19
MEAD HILL FORMATION															
42/12 M	333	89	46	16	8	11	5	4917	73	45	22	60	186	68	37
42/12 L	508	17	16	7	1	2	0	1244	23	9	5	15	55	19	9
4/3 M	268	41	21	9	2	8	0	114	16	8	7	7	26	8	6
4/3 L	185	12	7	6	0	2	0	102	16	8	6	5	22	1	6
30/14 M	350	33	16	7	3	4	3	1022	42	17	4	23	67	30	12
30/14 L	446	25	12	6	0	2	0	1776	21	13	2	17	51	14	9
20/4 L	256	27	10	7	2	3	2	786	26	15	11	11	45	5	7
20/2 L	308	18	10	5	1	3	0	595	21	12	6	14	33	6	8
104/1 M	353	41	34	11	3	9	3	549	35	23	24	38	100	48	33
104/1 L	338	17	19	5	0	3	1	463	17	9	14	26	47	19	17
Mean M	326	51	29	11	4	8	3	1651	42	23	14	32	95	39	22
Mean L	340	19	12	6	1	3	1	828	21	11	7	15	42	11	9
CLAVERLEY SANDSTONE															
50/3	204	39	18	8	3	5	1	215	46	50	16	29	55	7	17
43/11	145	30	32	7	3	5	2	240	29	26	22	34	60	9	24
10/3	99	37	9	8	3	6	4	300	36	25	13	29	34	1	15
Mean (43/11,10/3)	122	34	21	8	3	6	3	270	33	26	18	32	47	5	20
WOOLSHED FORMATION															
40/13	97	91	15	12	7	15	7	682	93	52	20	41	66	11	22
112/6	52	39	7	8	2	6	0	631	42	29	12	18	43	6	8
10/4	143	77	19	12	8	14	5	445	77	46	21	42	56	16	21
1/4	71	58	9	10	4	10	4	239	52	44	7	13	59	21	6
Mean	91	66	13	11	5	11	4	499	66	43	15	29	56	14	14

TABLE IIc: Insoluble Residue XRF (Major Element) Data.

SAMPLE NO.	MgO wt%	Na2O	SiO2	Al2O3	P2O5	Fe2O3	MnO	TiO2	K2O
WEKA PASS STONE									
42/5	1.93	2.18	70.32	13.34	.35	5.27	.06	.68	2.11
30/42	1.21	1.01	78.56	9.66	1.16	4.13	.10	.60	1.51
1/7	4.73	5.18	68.57	11.29	9.47	10.92	.49	.36	3.76
Mean	2.62	2.79	72.48	11.43	3.66	6.77	.21	.55	2.46
UPPER MARL									
50/20 M	3.03	.74	63.50	15.03	1.00	5.88	.07	.57	2.36
42/4 M	2.28	.72	72.98	13.02	.37	4.38	.10	.48	1.77
30/40 M	1.88	.74	71.42	13.41	.24	4.00	.03	.50	1.76
30/40 L	1.67	.79	69.06	13.28	.36	4.11	.09	.50	1.72
104/17 M	1.83	.83	76.11	13.87	.23	3.89	.11	.48	1.87
104/15 M	2.00	.55	58.96	18.77	.42	7.12	.15	.65	2.73
127/1 M	3.91	.79	64.86	15.46	.29	5.93	.16	.68	5.31
50/18 M	1.36	.81	74.76	9.01	.24	2.99	.06	.33	1.63
50/17 M	1.53	.79	78.05	10.13	.18	3.10	.03	.39	1.62
50/17 L	1.32	.95	82.35	7.50	.36	2.58	.18	.18	1.14
42/6 M	2.91	.94	77.79	15.72	.49	4.00	.24	.55	1.94
30/37 M	1.87	.84	74.74	15.48	.27	4.69	.05	.61	1.97
30/37 L	1.43	.74	81.24	10.49	.29	3.07	.04	.37	1.21
15/8 M	2.57	2.16	65.37	14.51	.43	3.66	.10	.52	3.04
15/8 L	2.14	2.27	72.01	11.57	.44	3.08	.06	.38	2.39
104/16 M	1.54	1.13	73.65	12.41	.13	2.83	.15	.51	1.98
104/16 L	1.81	.77	69.31	13.08	.18	2.97	.27	.47	1.78
Mean M	2.23	.92	71.02	13.90	.36	4.37	.10	.52	2.33
Mean L	1.67	1.10	74.80	11.19	.33	3.16	.13	.38	1.65
FELLS GREENSAND									
50/18	.47	.65	90.74	3.18	.05	2.44	.02	.11	1.20
42/7	.43	1.12	93.57	4.99	.08	2.02	.02	.17	1.42
105/3	.47	1.38	87.08	5.89	.03	2.28	.04	.28	1.95
104/17	.62	.21	88.75	2.96	.07	3.93	.03	.05	1.82
104/16	.67	1.75	78.17	7.92	.06	1.90	.12	.33	1.81
Mean	.53	1.02	90.26	4.99	.06	2.52	.04	.19	1.64

TABLE IIc: Insoluble Residue XRF (Major Element) Data.

SAMPLE NO.	MgO wt%	Na2O	SiO2	Al2O3	P2O5	Fe2O3	MnO	TiO2	K2O
MIDDLE LIMESTONE									
50/26 M	2.93	.44	59.81	14.19	.42	5.53	.23	.47	2.28
50/26 L	2.19	.57	75.14	10.39	.56	3.76	.25	.31	1.57
42/7 M	.79	.79	93.02	4.38	.29	1.58	.22	.07	.43
42/7 L	.98	1.34	91.20	5.93	.33	2.93	.33	.08	.57
32/1 L	1.72	1.40	82.99	8.42	.86	2.75	.69	.00	.52
30/35 M	3.06	.62	57.46	19.26	1.39	4.25	.24	.62	2.68
30/35 L	.90	1.58	88.50	7.89	.56	2.25	.34	.11	.56
20/15 L	.77	.51	95.69	3.78	.38	1.22	.19	.00	.26
Mean M	2.26	.62	73.43	12.61	.70	3.79	.23	.39	1.80
Mean L	1.31	1.08	89.91	7.28	.54	2.58	.36	.10	.69
LOWER MARL									
50/16 M	2.23	.82	58.56	13.65	.48	3.61	.19	.48	1.79
50/16 L	1.44	.44	66.97	9.83	.32	2.41	.12	.36	1.36
30/32 M	2.23	.55	68.42	14.79	.37	4.56	.22	.51	1.72
30/32 L	1.06	.39	81.25	7.69	.24	2.85	.24	.20	.77
128/4 M	2.58	.45	69.99	17.06	.45	4.74	.05	.63	2.08
30/30 M	2.02	.37	73.80	15.66	.27	4.56	.12	.57	2.09
30/30 L	1.20	.40	78.94	7.49	.27	2.44	.27	.21	.82
128/3 M	2.29	.39	69.70	15.68	.22	3.83	.03	.62	1.91
128/3 L	1.40	.48	79.99	8.34	.43	2.76	.16	.31	1.02
50/11 M	2.57	.67	66.00	14.38	.56	3.46	.17	.53	1.84
50/11 L	.69	.55	89.65	4.88	.26	1.28	.20	.13	.75
30/27 M	2.24	.46	73.16	14.00	.36	3.73	.10	.51	1.98
30/27 L	1.15	1.43	73.31	7.02	.32	2.02	.32	.22	.94
Mean M	2.31	.53	68.52	15.03	.39	4.07	.13	.55	1.92
Mean L	1.16	.62	78.35	7.54	.31	2.29	.22	.24	.95
LOWER LIMESTONE									
20/5 L	.71	1.05	88.89	4.22	.77	1.88	.09	.15	1.14
104/5 L	1.24	1.31	74.18	7.46	.95	3.78	.55	.20	1.00
30/22 M	3.17	.83	64.34	12.04	1.27	5.16	.36	.45	2.08
30/22 L	1.59	.45	81.40	7.48	.71	2.48	.31	.22	1.11

TABLE IIc: Insoluble Residue XRF (Major Element) Data.

SAMPLE NO.	MgO wt%	Na2O	SiO2	Al2O3	P2O5	Fe2O3	MnO	TiO2	K2O
TEREDO LIMESTONE									
5/1	1.52	3.04	93.68	7.84	.68	3.40	.12	.20	2.76
50/24	.48	2.26	80.61	8.75	.22	1.50	.07	.60	2.71
MEAD HILL FORMATION									
42/12 M	5.38	.46	68.78	13.13	.39	3.84	.04	.50	2.96
42/12 L	1.89	.30	87.31	4.34	.16	1.25	.04	.15	.86
4/3 M	1.13	1.55	82.05	8.53	.18	2.36	.04	.34	1.35
4/3 L	.30	.45	96.39	2.14	.05	.48	.04	.08	.38
30/14 M	2.74	.39	86.04	7.15	.28	1.98	.15	.28	1.77
30/14 L	2.11	.32	91.73	4.02	.19	1.03	.06	.14	.98
20/4 L	.60	.64	90.73	4.21	.07	.99	.02	.16	.75
20/2 L	.43	.54	92.69	3.17	.07	.94	.04	.13	.56
104/1 M	4.69	.56	76.11	7.49	.26	3.73	.29	.31	1.79
104/1 L	2.78	.40	90.49	3.77	.15	1.74	.32	.13	.79
Mean M	3.49	.74	78.25	9.07	.28	2.98	.13	.36	1.97
Mean L	1.35	.44	91.56	3.61	.11	1.07	.09	.13	.72
CLAVERLEY SANDSTONE									
50/3	.68	1.10	86.47	5.59	.28	2.16	.04	.20	1.26
43/11	.47	.95	90.97	4.65	1.04	1.17	.01	.17	.84
10/3	.60	2.49	86.03	7.65	.06	1.33	.03	.23	1.20
Mean (43/11,10/3)	.58	1.51	87.82	5.96	.46	1.55	.03	.20	1.10
WOOLSHED FORMATION									
40/13	1.84	2.35	72.93	13.61	.07	3.71	.03	.59	2.44
112/6	.82	.72	89.16	5.23	.04	1.47	.02	.24	.99
10/4	1.57	3.04	81.86	14.21	.10	3.74	.03	.59	2.22
1/4	1.43	1.71	85.62	8.90	.11	2.90	.03	.41	1.57
Mean	1.42	1.96	82.39	10.49	.08	2.96	.03	.45	1.81

TABLE IId: Insoluble Residue XRF (Trace Element) Data.

SAMPLE NO.	Rb ppm	Y	Pb	Th	Ga	Nb	Ba	V	Cr	Nd	Ce	Zn	Ni	La
WEKA PASS STONE														
42/5	92	24	13	6	15	6	417	123	110	22	55	99	46	22
30/42	65	70	25	0	10	10	659	126	106	35	81	141	45	81
1/7	109	595	49	0	12	24	24	352	255	146	206	328	291	328
Mean	89	230	29	2	12	13	367	200	157	68	114	189	127	143
UPPER MARL														
50/20 M						7	475	226	76	7	76	180	83	47
42/4 M	112	20	27	3	10	7	415	136	58	0	51	122	48	31
30/40 M	79	26	21	6	18	9	2870	115	56	12	44	138	56	29
30/40 L	167	59	27	5	14	0	3780	140	59	0	50	117	54	45
104/17 M	74	36	17	4	13	11	2484	124	67	19	50	120	65	25
104/15 M	112	23	31	4	8	0	7023	127	54	8	100	108	46	46
127/1 M	117	21	19	8	17	10	243	132	86	19	62	134	89	23
50/18 M	48	30	18	6	9	6	4770	88	45	6	70	85	30	42
50/17 M						0	3217	99	36	0	48	111	57	30
50/17 L						0	1651	120	30	0	42	96	36	48
42/6 M						0	4478	140	49	0	121	127	121	79
30/37 M	74	20	20	7	7	7	1951	133	64	0	47	113	59	27
30/37 L	150	33	26	11	18	0	4351	121	44	11	55	69	33	37
15/8 M	90	57	209	5	5	10	8363	152	52	14	81	128	57	38
15/8 L	69	50	38	0	0	0	9591	145	31	0	107	119	57	31
104/16 M	20	20	9	0	2	4	3024	81	51	0	68	57	42	18
104/16 L	71	27	18	0	9	6	4425	86	50	24	53	59	44	27
Mean M	81	28	41	5	10	6	3276	129	58	7	68	119	63	36
Mean L	114	42	27	4	10	1	4760	122	43	7	61	92	45	38
FELLS GREENSAND														
50/18	40	6	10	0	2	0	2562	43	35	0	14	32	5	3
42/7						2	1714	40	28	0	13	46	33	6
105/3	63	6	10	3	4	1	733	42	54	0	12	31	7	1
104/17	61	5	8	1	3	0	291	50	76	0	16	33	3	4
104/16						0	1154	56	35	0	15	0	17	10
Mean	54	6	9	1	3	1	1291	46	46	0	14	28	13	5

TABLE IId: Insoluble Residue XRF (Trace Element) Data.

SAMPLE NO.	Rb ppm	Y	Pb	Th	Ga	Nb	Ba	V	Cr	Nd	Ce	Zn	Ni	La
MIDDLE LIMESTONE														
50/26 M	88	51	23	5	9	9	5544	107	56	0	93	116	70	47
50/26 L	63	56	31	0	0	13	5272	106	19	0	113	88	238	50
42/7 M	158	72	36	0	7	14	4106	86	14	0	57	65	43	36
42/7 L	390	98	65	16	57	0	1407	122	24	0	57	57	24	57
32/1 L	17	120	69	0	0	0	28282	189	0	0	86	69	103	120
30/35 M	139	158	43	24	29	10	1960	258	96	110	167	229	167	33
30/35 L	11	90	79	0	11	0	812	158	0	0	113	79	56	101
20/15 L	6	32	32	0	0	0	5183	70	0	0	83	51	13	38
Mean M	128	94	34	10	15	11	3870	150	55	37	106	137	93	39
Mean L	98	79	55	3	14	3	8191	129	9	0	90	69	87	73
LOWER MARL														
50/16 M	160	45	41	11	22	7	37474	52	33	0	67	89	41	30
50/16 L	16	24	12	0	0	8	81108	0	8	0	52	56	16	24
30/32 M	190	51	47	22	37	7	4827	99	58	11	73	91	37	40
30/32 L	69	53	28	4	4	0	6893	65	24	0	65	73	16	33
128/4 M	84	29	18	5	11	5	5859	132	55	16	74	111	55	39
30/30 M	77	67	20	5	12	7	5156	92	57	2	67	90	60	32
30/30 L	45	41	14	0	0	0	8045	58	27	0	72	45	10	38
128/3 M	36	16	9	0	3	10	1307	126	60	22	53	85	38	26
128/3 L	53	31	19	0	3	3	1086	71	34	12	65	56	25	40
50/11 M	8	14	11	0	0	6	5779	101	59	28	114	106	114	59
50/11 L	118	52	33	7	16	3	9535	36	16	0	46	33	29	20
30/27 M	51	27	12	0	0	7	6046	94	58	17	55	101	94	34
30/27 L	104	22	29	4	7	0	6578	119	50	7	94	101	43	43
Mean M	87	35	23	6	12	7	9493	99	54	14	72	96	63	37
Mean L	67	37	22	2	5	2	18874	58	27	3	66	61	23	33
LOWER LIMESTONE														
20/5 L	45	88	13	0	6	4	950	69	116	45	62	53	15	73
104/5 L	45	109	30	0	10	10	5070	75	40	55	114	129	70	95
30/22 M	86	131	36	14	14	9	7796	122	63	41	149	249	303	95
30/22 L	44	80	35	0	0	9	9030	84	35	0	93	142	71	62

TABLE IId: Insoluble Residue XRF (Trace Element) Data.

SAMPLE NO.	Rb ppm	Y	Pb	Th	Ga	Nb	Ba	V	Cr	Nd	Ce	Zn	Ni	La
TEREDO LIMESTONE														
5/1	64	40	24	0	0	0	364	72	44	24	56	64	32	24
50/24	47	17	9	4	9	12	543	88	75	20	47	57	79	25
MEAD HILL FORMATION														
42/12 M	120	62	22	11	15	7	6647	99	61	30	81	251	92	50
42/12 L	31	29	13	2	4	0	2280	42	16	9	27	101	35	16
4/3 M	56	29	12	3	11	0	157	22	11	10	10	36	11	8
4/3 L	15	8	7	0	2	0	124	19	10	7	6	27	1	7
30/14 M	70	34	15	6	9	6	2174	89	36	9	49	143	64	26
30/14 L	36	17	9	0	3	0	2533	30	19	3	24	73	20	13
20/4 L	33	12	9	2	4	2	968	32	18	14	14	55	6	9
20/2 L	24	13	7	1	4	0	800	28	16	8	19	44	8	11
104/1 M	70	58	19	5	15	5	944	60	40	41	65	172	83	57
104/1 L	32	36	9	0	6	2	868	32	17	26	49	88	36	32
Mean M	79	46	17	6	12	5	2481	68	37	22	51	150	62	35
Mean L	28	19	9	1	4	1	1262	31	16	11	23	65	18	15
CLAVERLEY SANDSTONE														
50/3	49	23	10	4	6	1	270	58	63	20	36	69	9	21
43/11	32	34	7	3	5	2	252	31	27	23	36	63	9	25
10/3	39	9	8	3	6	4	315	38	26	14	30	36	1	16
Mean (43/11,10/3)	40	22	9	3	6	3	279	42	39	19	34	56	6	21
WOOLSHED FORMATION														
40/13	95	16	13	7	16	7	714	97	54	21	43	69	12	23
112/6	40	7	8	2	6	0	646	43	30	12	18	44	6	8
10/4	85	21	13	9	16	6	494	85	51	23	47	62	18	23
1/4	63	10	11	4	11	4	258	56	47	8	14	64	23	6
Mean	71	13	11	6	12	4	528	70	46	16	30	60	15	15

TABLE IIe: Whole Rock Mineralogy.

SAMPLE NO.	CaCO3 wt%	I+S(+K+Z)	Q(+C)	Illite	Smectite	Kaolinite	Zeolite	Feldspar
WEKA PASS STONE								
42/5	46		++	+	++	+		+
30/42	80	7	13	0	7			
1/7	92	5	3	+	+		++	
UPPER MARL								
50/20 M	70	22	9	+	++		++	
42/4 M	71	15	15	+	++			
30/40 M	66	17	17	4	14			
30/40 L	78	13	10	2	11			
104/17 M	52	23	24	5	19			
104/15 M	74	20	6	+	++	+		
127/1 M	49	0	0	+	++			+
50/18 M	67	15	18	+	++		+	
50/17 M	67	14	19	0	14			
50/17 L	83	6	11	0	6			
42/6 M	84	8	8	2	6			
30/37 M	59	18	23	4	13			
30/37 L	73	11	17	1	10			
15/8 M	79	15	6	+	+		+++	
15/8 L	84	7	9	+	++		+++	
104/16 M	54	23	23	4	19	+		
104/16 L	66	19	15	5	15			
FELLS GREENSAND								
50/18	38	0	+++	0	0			
42/7	37	0	+++	0	0			+
105/3	31	0	+++	0	0			+
104/17	24	0	+++	0	0			+
104/16	48	0	+++	0	0			+

TABLE IIe: Whole Rock Mineralogy.

SAMPLE NO.	CaCO3 wt%	I+S(+K+Z)	Q(+C)	Illite	Smectite	Kaolinite	Zeolite	Feldspar
MIDDLE LIMESTONE								
50/26 M	79	17	4	2	15			
50/26 L	84	8	8	1	6			
42/7 M	86	2	12	0	2			
42/7 L	88	1	11	0	1			
32/1 L	94	1	4	0	1			
30/35 M	79	16	5	4	12			
30/35 L	91	2	7	0	2			
20/15 L	84	2	14	0	2			
LOWER MARL								
50/16 M	73	20	6	+	+		++	
50/16 L	75	8	13		++		++	
30/32 M	73	17	10	3	15			
30/32 L	75	6	19	1	5			
128/4 M	62	23	15	4	19			
128/3 M	42	34	24	7	27			
128/3 L	68	11	21	3	8			
30/30 M	60	19	21	4	14			
30/30 L	71	9	20	2	7			
50/11 M	64	22	13	4	18			
50/11 L	69	5	26	+	+			
30/27 M	59	21	21	4	17			
30/27 L	72	14	14	2	12			
LOWER LIMESTONE								
20/5 L	47	9	44	0	9	+		
104/5 L	80	8	12	0	8			
30/22 M	78	13	9	4	9			
30/22 L	77	8	15	0	8			

TABLE IIe: Whole Rock Mineralogy.

SAMPLE NO.	CaCO3 wt%	I+S(+K+Z)	Q(+C)	Illite	Smectite	Kaolinite	Zeolite	Feldspar
TEREDO LIMESTONE								
5/1	70	11	19	+	0		+++	
50/24	23	0	+++	0	0			+
MEAD HILL FORMATION								
42/12 M	26	44	29	+	++			
42/12 L	45	11	43	0	11			
4/3 M	27	23	50	0	23			
4/3 L	17	6	77	0	6			
30/14 M	53	14	33	0	14			
30/14 L	30	12	59	0	12			
20/4 L	19	15	66	0	15			
20/2 L	26	10	64	0	10			
104/1 M	42	27	31	0	27			
104/1 L	47	8	45	0	8			
CLAVERLEY SANDSTONE								
50/3	20		+++	+	+			+
43/11	5		+++					+
10/3	5		+++		+	+		++
WOOLSHED FORMATION								
40/13	5		+++	+	+	+		+
112/6	2	18	80		+	+		+
10/4	10		+++	+	+	+		+
1/4	7	25	68	+	+	+		

TABLE IIf: Insoluble Residue Mineralogy.

SAMPLE NO.	wt%	I+S(+K+Z)	Q(+C)	Cristobalite	Illite	Smectite	Kaolinite	Zeolite	Feldspar	Barite	Glc
WEKA PASS STONE											
42/5			+++	+	+	++	+		+		+
30/42		37	63		0	37					+
1/7		60	40	++	?+	+		++			+
UPPER MARL											
50/20 M		72	28	++	+	++		++			
42/4 M		51	49	++	+	++					
30/40 M		51	49		11	41					
30/40 L		57	43		9	48					
104/17 M		49	51		10	39					
104/15 M		77	23		+	++	+			1	
127/1 M					+	++			+		
50/18 M		45	55	++	+	++		+			
50/17 M		43	57	+++	0	43					
50/17 L		35	65	++	0	35					
42/6 M		50	50	+	12	38					
30/37 M		43	57		10	33					
30/37 L		40	60		3	37					
15/8 M		69	31		+	+		+++		1	
15/8 L		46	54	++	+	++		+++		2	
104/16 M		51	49	+	8	42	+				
104/16 L		57	43	+	14	43					
FELLS GREENSAND											
50/18			+++		0	0					+
42/7			+++		0	0			+		+
105/3			+++		0	0			+		+
104/17			+++		0	0			+		+
104/16			+++	+		+			+		+

TABLE IIf: Insoluble Residue Mineralogy.

SAMPLE NO.	wt%	I+S(+K+Z)	Q(+C)	Cristobalite	Illite	Smectite	Kaolinite	Zeolite	Feldspar	Barite	Glc
MIDDLE LIMESTONE											
50/26 M		80	20		8	72				1	
50/26 L		48	52		9	39				1	
42/7 M		16	84		0	16					
42/7 L		10	90		0	10					
32/1 L		23	72		3	20				5	
30/35 M		75	25		18	57					
30/35 L		21	79	+	0	21					
20/15 L		11	89		0	11					
LOWER MARL											
50/16 M		73	21	+	+	+		++		6	
50/16 L		32	54	++		++		++		14	
30/32 M		63	37		9	54				1	
30/32 L		23	77		3	20				1	
128/4 M		61	39		11	50				1	
128/3 M		59	41		12	47					
128/3 L		35	65		9	26					
30/30 M		47	53		11	36				1	
30/30 L		31	69		6	25				1	
50/11 M		63	37		12	51				1	
50/11 L		15	85	+++	+	+				2	
30/27 M		50	50		9	41				1	
30/27 L		51	49		7	44				1	
LOWER LIMESTONE											
20/5 L		18	82		0	18			+		
104/5 L		40	60		0	40					
30/22 M		57	43		17	40				1	
30/22 L		34	66		0	34				2	

TABLE IIf: Insoluble Residue Mineralogy.

SAMPLE NO.	wt% I+S(+K+Z)	Q(+C)	Cristobalite	Illite	Smectite	Kaolinite	Zeolite	Feldspar	Barite	Glc
TEREDO LIMESTONE										
5/1	36	64	++	+			+++			+
50/24		+++		0	0			+		+
MEAD HILL FORMATION										
42/12 M	60	40	++	+	++				1	
42/12 L	21	79		0	21				0	
4/3 M	31	69	++	0	31					
4/3 L	7	93	+++	0	7					
30/14 M	30	70		0	30					
30/14 L	17	83		0	17					
20/4 L	19	81		0	19					
20/2 L	14	86	+	0	14					
104/1 M	46	54		0	46					
104/1 L	16	84		0	16					
CLAVERLEY SANDSTONE										
50/3		+++		+	+			+		+
43/11		+++						+		+
10/3		+++			+	+		++		+
WOOLSHED FORMATION										
40/13		+++	+	+	+	+		+		
112/6	19	81			+	+		+		
10/4		+++	++	+	+	+		+		
1/4	27	73	+++	+	+	+				

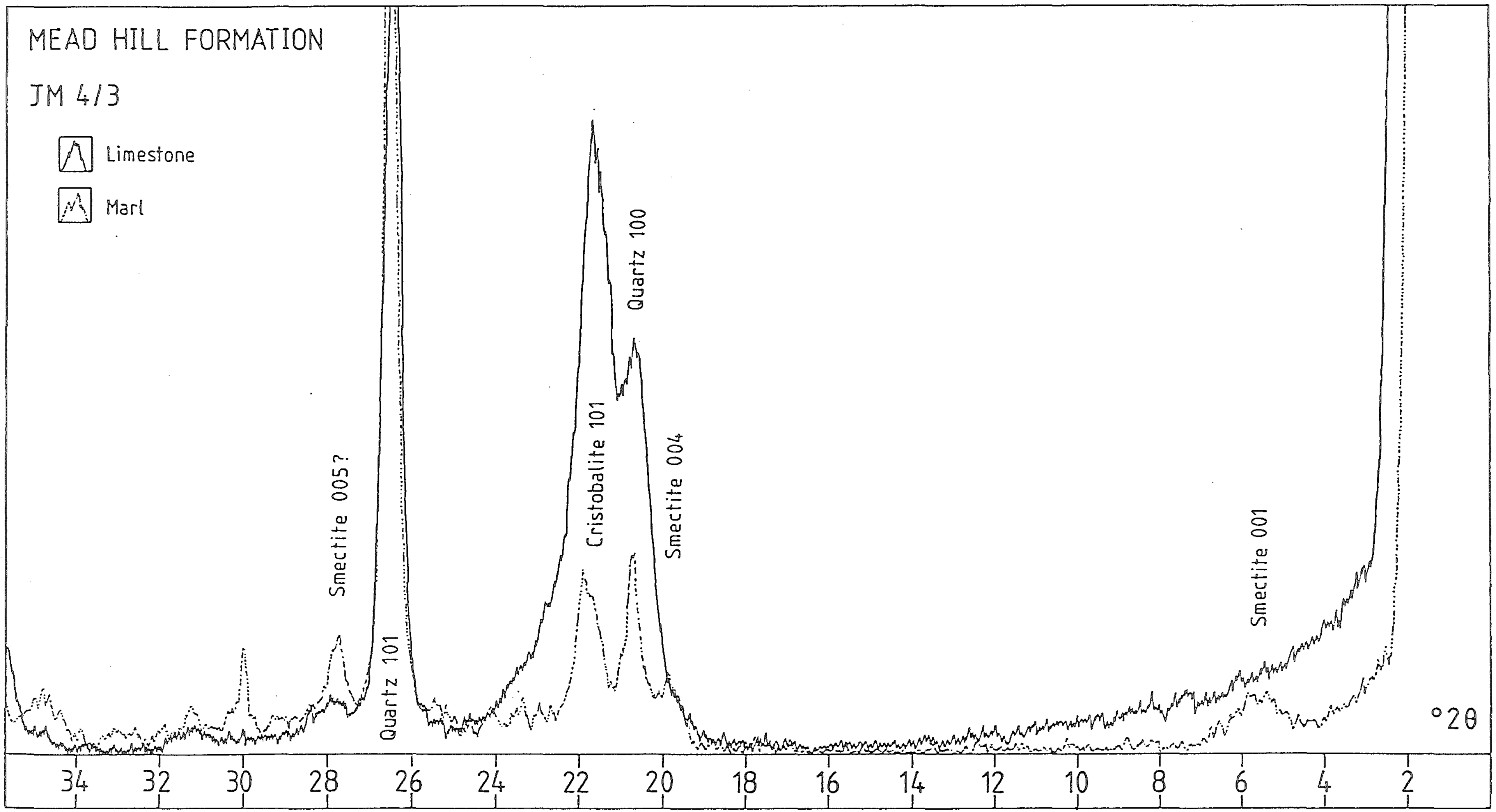
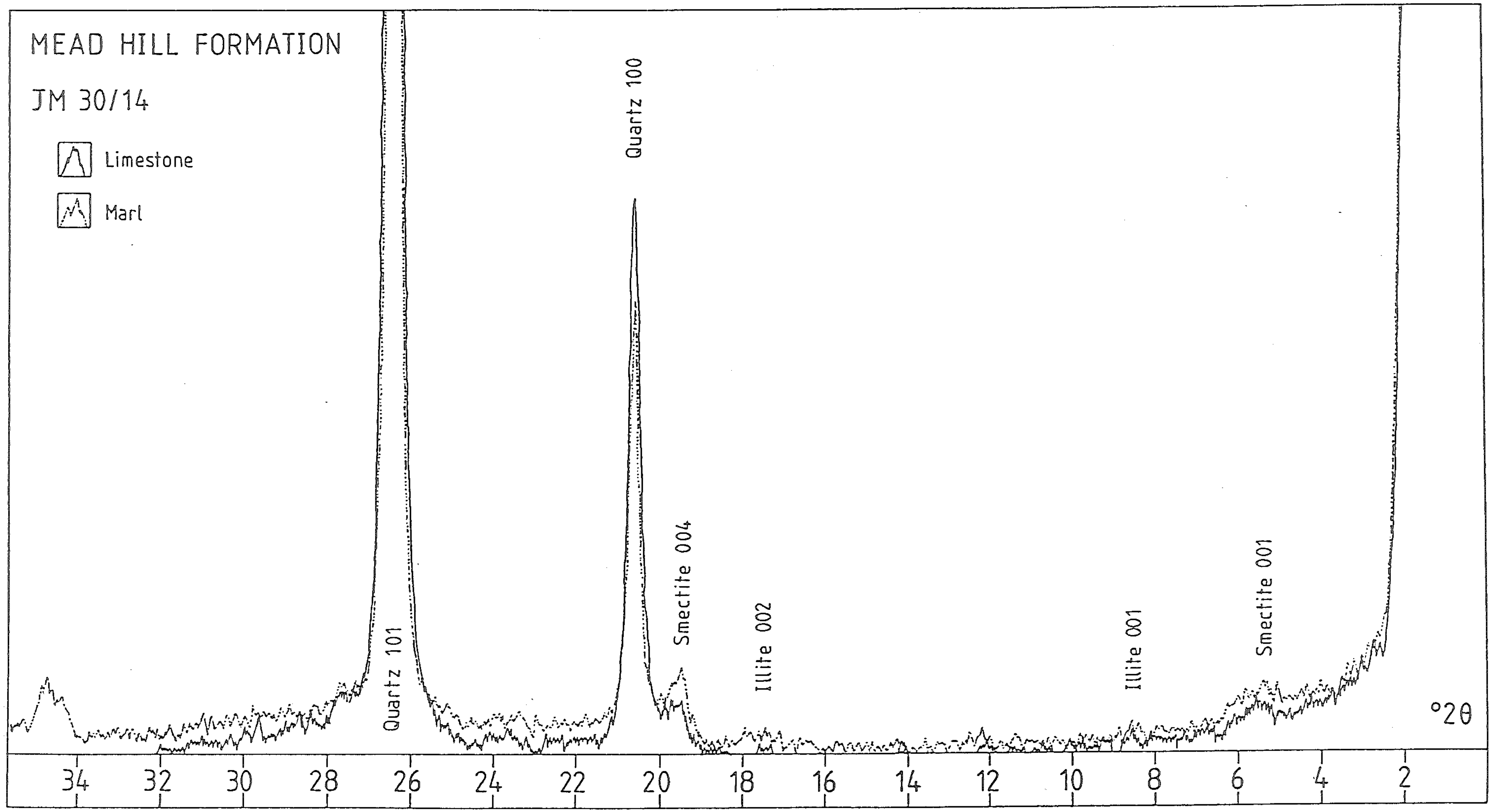


Figure II.a: Insoluble residue XRD trace of Mead Hill Formation.

Figure II.b: Insoluble residue XRD trace of Mead Hill Formation.



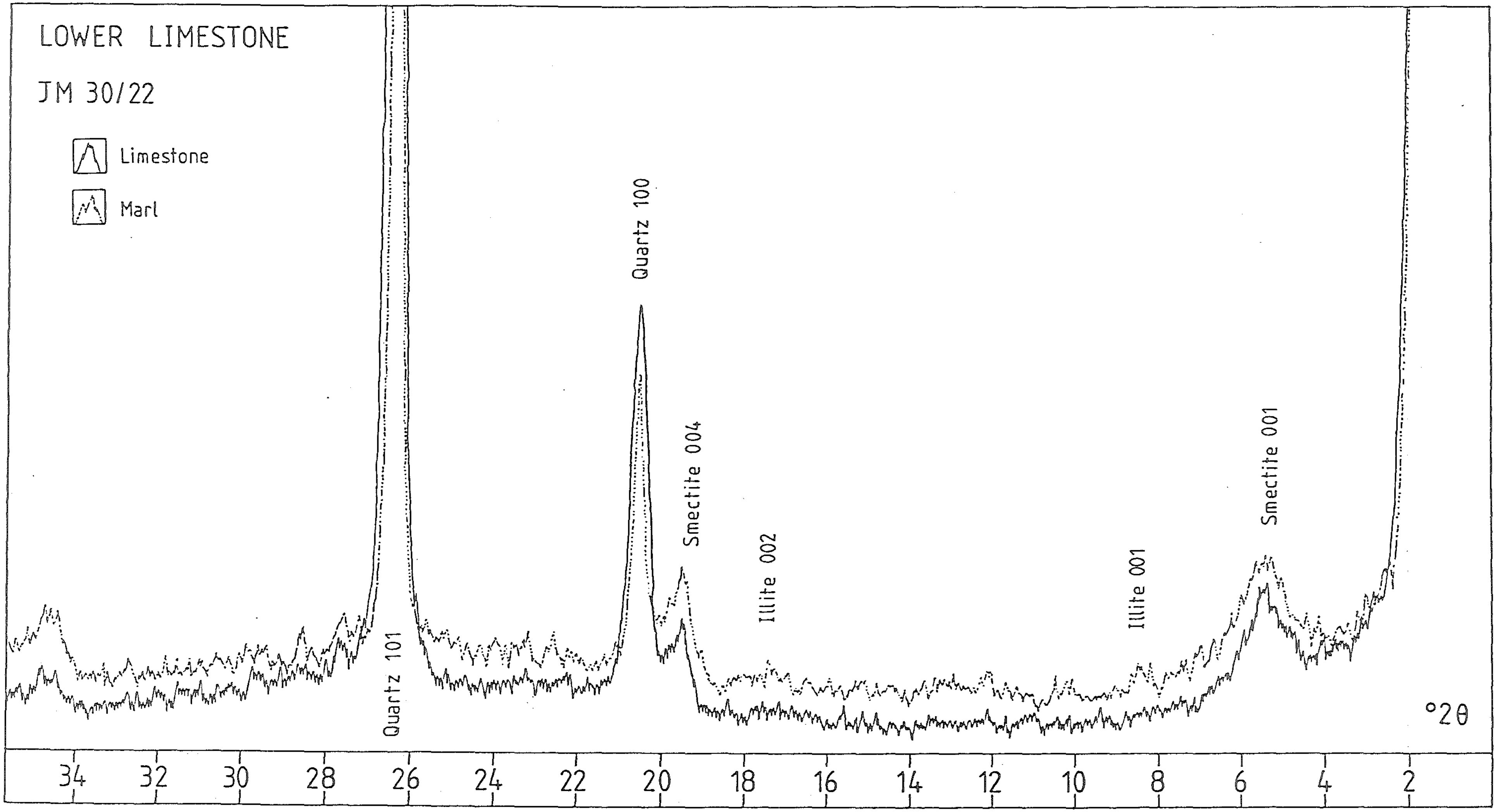
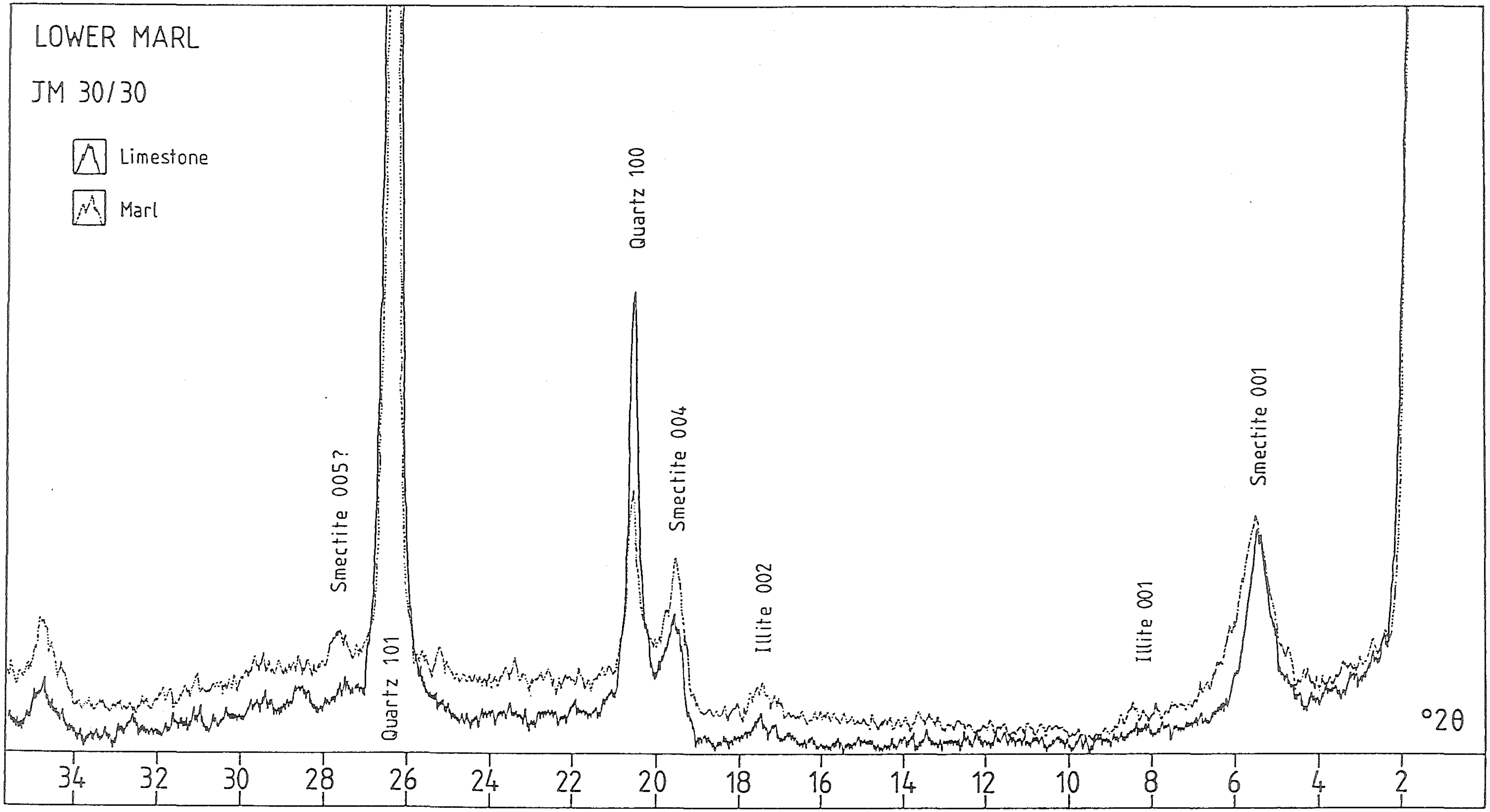


Figure II.c: Insoluble residue XRD trace of Lower Limestone.

Figure II.d: Insoluble residue XRD trace of Lower Marl.



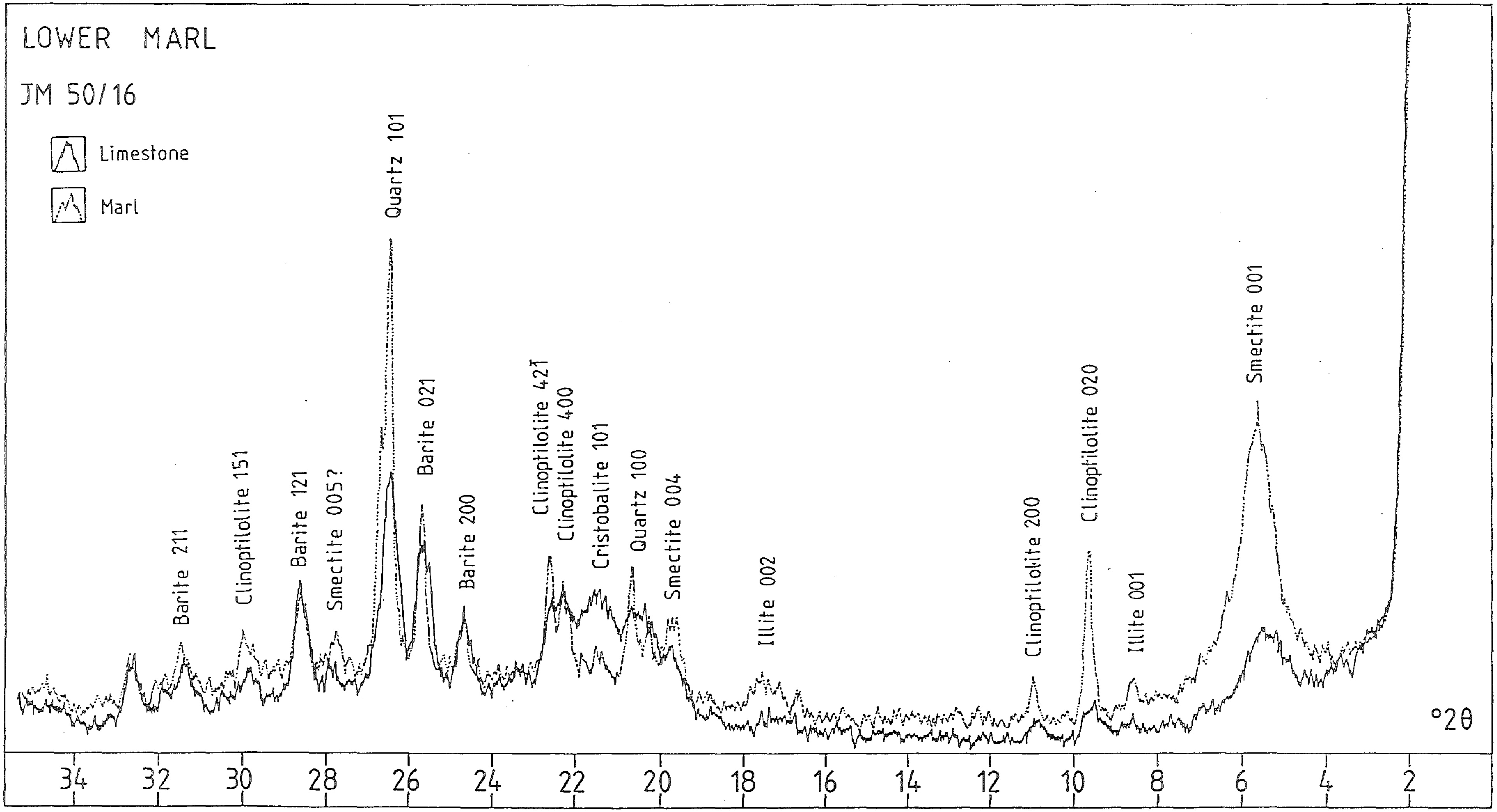
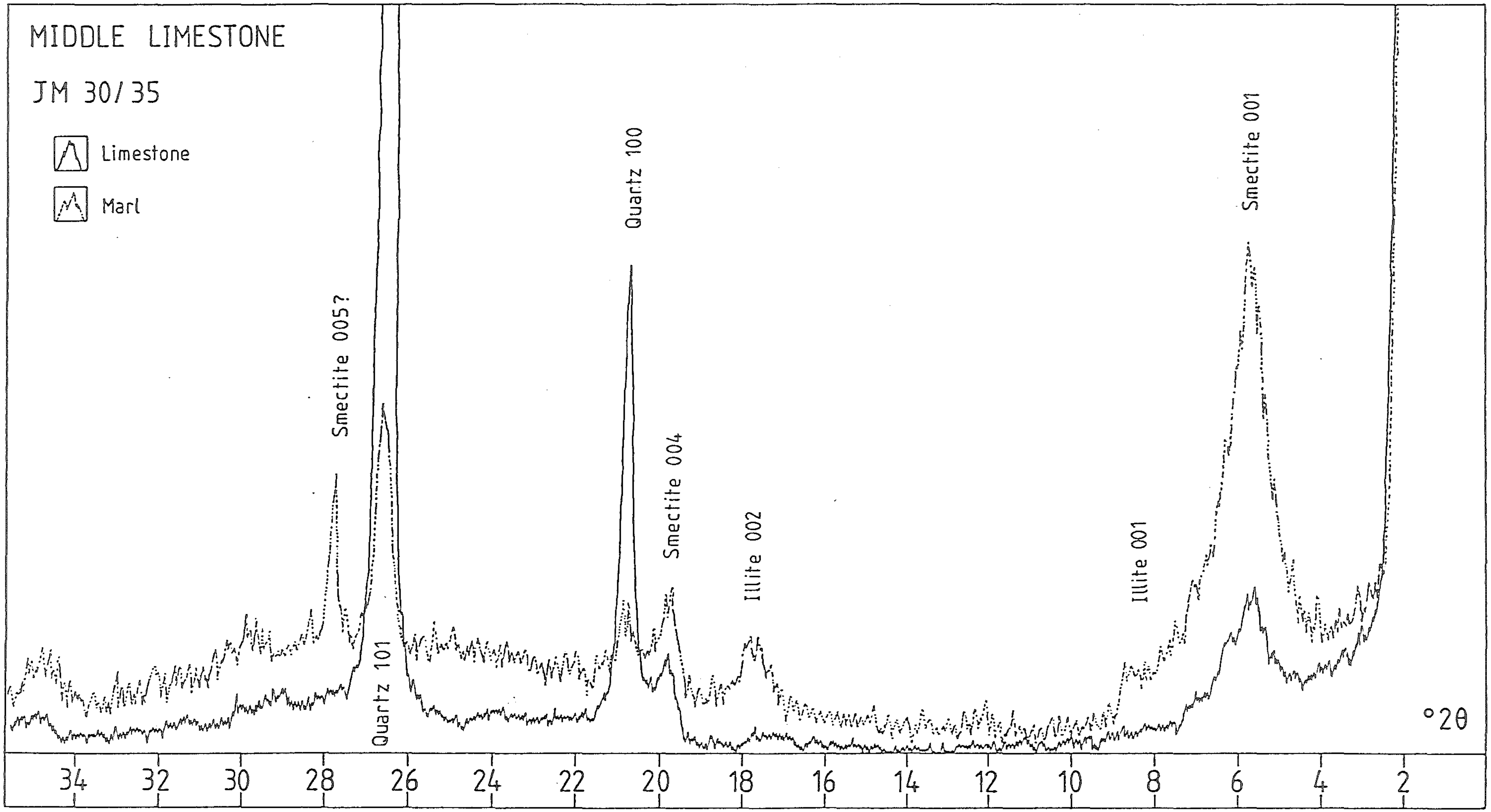


Figure II.e: Insoluble residue XRD trace of Lower Marl.

Figure II.f: Insoluble residue XRD trace of Middle Limestone.



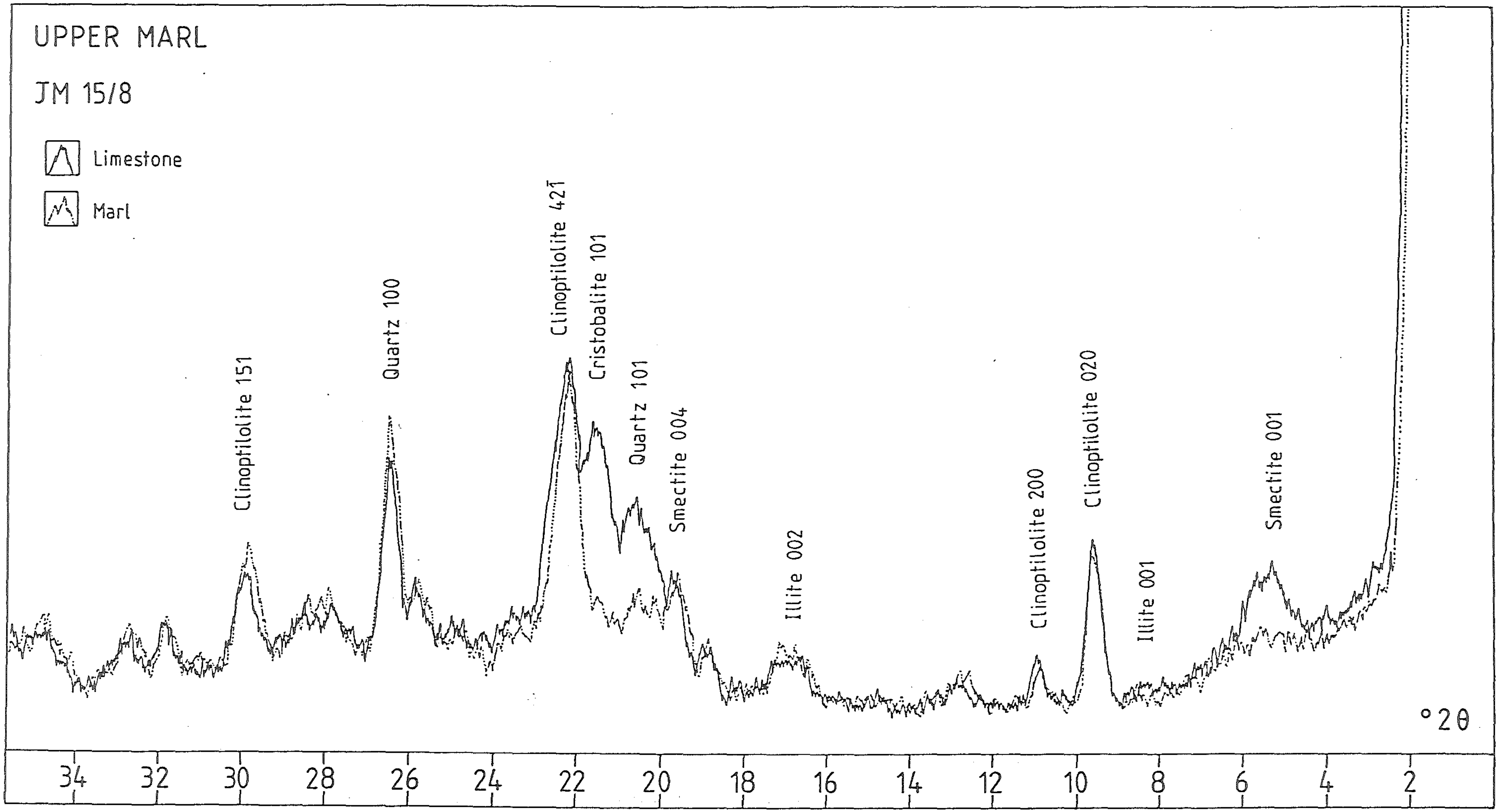
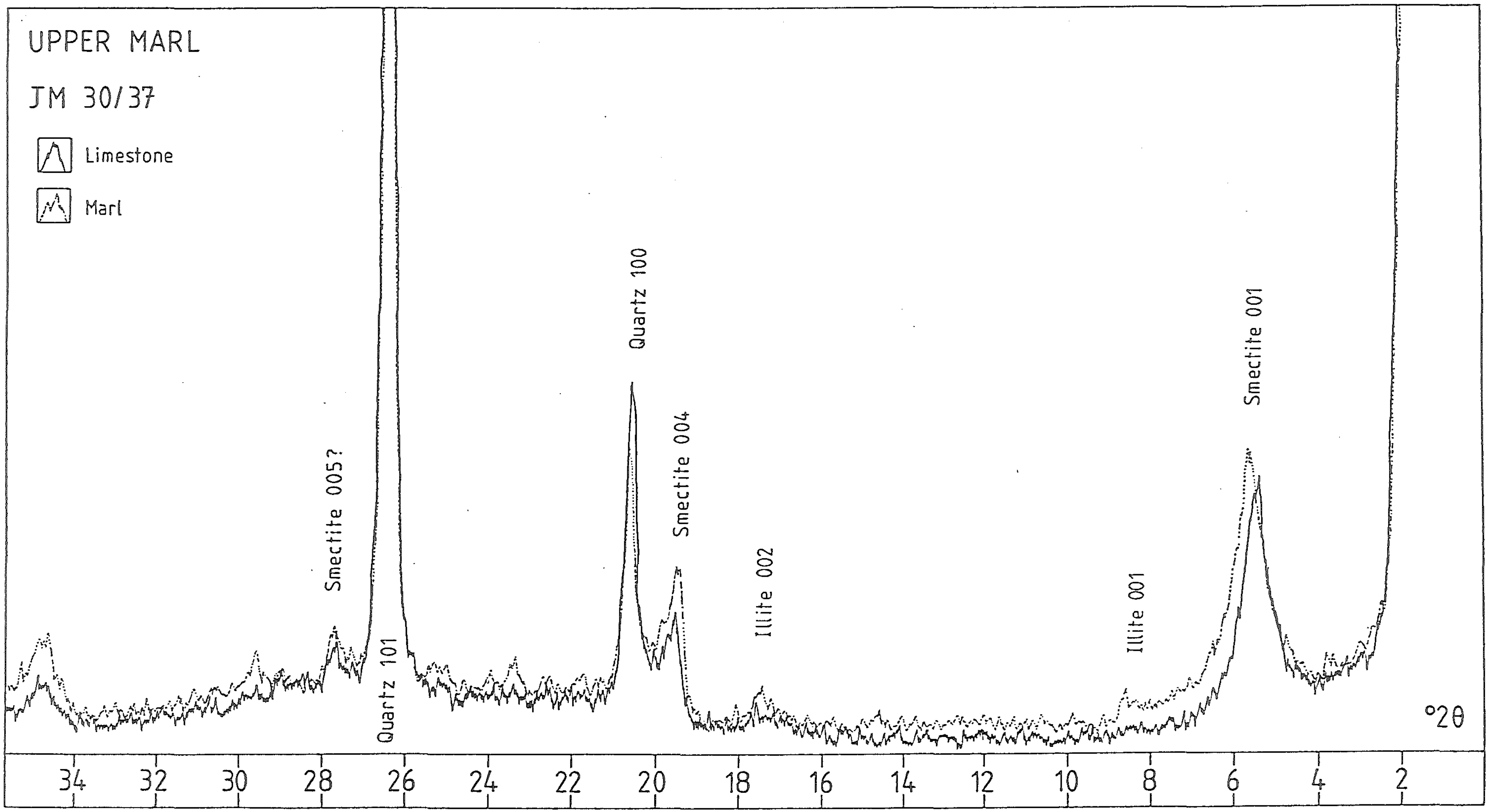


Figure II.g: Insoluble residue XRD trace of Upper Marl.

Figure II.h: Insoluble residue XRD trace of Upper Marl.



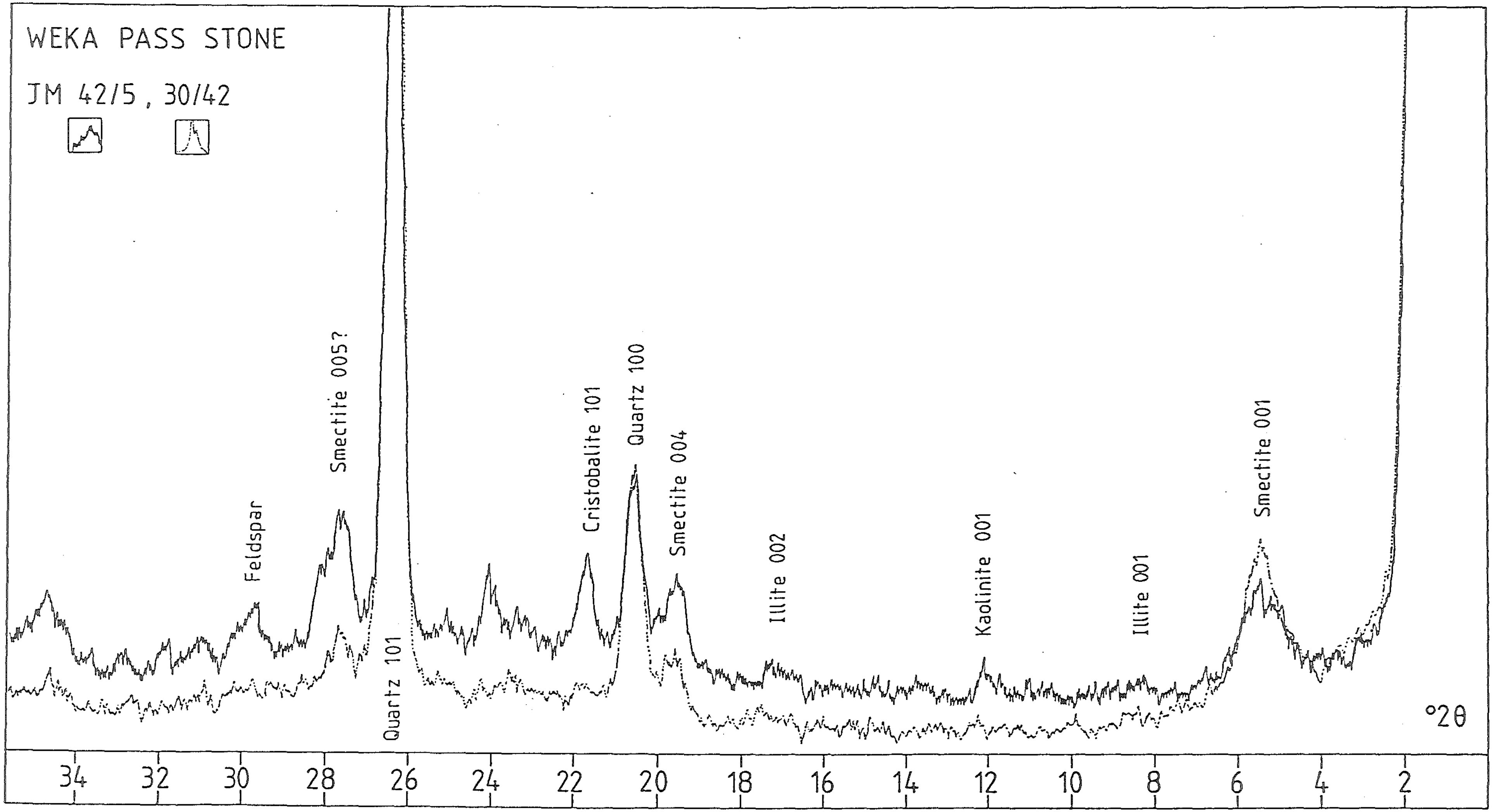


Figure II.i: Insoluble residue XRD trace of Weka Pass Stone.

APPENDIX III: SANDSTONE PETROGRAPHIC DESCRIPTIONS

KEY

Qm = Monocrystalline quartz.

Qp = Polycrystalline quartz grains (excluding chert).

Fp = Monocrystalline plagioclase.

Fk = Monocrystalline K-feldspar.

L = Lithic fragments.

M = Mica.

Py = Pyrite.

Fbth = Benthic foraminifera.

Fplk = Planktic foraminifera.

Glc = Glauconite.

Mtx = Matrix.

Other = Fossil fragments, rip-up clasts, etc.

Cmt = Cement.

TABLE IIIa:
Summary of modal composition of Claverley Sandstone plus additional lithologies that may be genetically related to that unit.

Sample	12/1	25/8	6/4	25/7	18/6	10/3	4/2	4/1	Mean
Qm	38.5	33.7	54.6	47.3	32.5	46.3	25.0	30.0	38.5
Qp	17.0	2.8	21.7	18.7	6.1	13.7	4.4	3.1	10.9
Fp	5.0	2.0	2.3	2.3	3.5	3.3	1.9	1.5	2.7
Fk	5.3	2.8	5.2	5.0	2.0	5.0	2.4	1.0	3.6
L	4.0	1.0	3.5	3.5	3.2	2.0	.5	.1	2.2
M	1.0	1.2	.2	1.2		1.1	.5	.1	.7
Py	.5	.5	.3	.2		.6	.1	.2	.3
Fbth		.5			.2		.9	.7	.3
Fplk		2.2			1.9		2.1	.3	.8
Glc	.5	1.0	1.5	.8	4.0	.5	4.1	11.1	2.9
Mtx		51.8	10.5	9.0	46.0	14.5	57.3	50.6	30.0
Other		.5		.1	.1		.7	1.3	.3
Cmt	28.2			12.2		13.0			6.7
Q*	79.6	86.2	86.4	86.4	87.2	85.3	86.1	92.6	86.2
F*	14.7	11.4	8.5	9.1	5.9	11.8	12.5	7.0	10.1
L*	5.7	2.4	5.1	4.4	6.9	2.9	1.4	.4	3.7

Additional Lithologies

Sample	300/8	300/6	704/1	40/12	10/4	SS 1
Qm	57.0	46.8	69.0	59.0	53.5	52.7
Qp	2.5	7.0	5.0	6.8	3.8	5.2
Fp	1.3	1.7	6.0	2.3	2.0	1.8
Fk	5.5	2.2	4.5	9.3	5.0	4.0
L	4.2	5.9	12.5	2.5	2.0	3.2
M	2.5					2.2
Py			3.0			.8
Fbth						
Fplk		.1				
Glc	4.8	1.2		1.8	2.8	.8
Mtx				18.5		7.3
Other					.2	
Cmt	24.0	35.2	3.5		30.8	22.0
Q*	84.4	84.6	76.2	83.0	86.4	86.6
F*	9.6	6.0	10.9	14.5	10.6	8.7
L*	6.0	9.4	12.9	2.5	3.0	4.7

TABLE IIIb:
Summary of modal composition of Teredo Limestone plus additional lithologies that may be genetically related to that unit.

Sample	5/1	128/1	122/3	4/5	52/5	43/17	1/2	12/3	20/5
Qm	6.3	21.3	33.9	19.8	39.8	18.2	18.8	28.7	8.8
Qp	4.2	6.0	5.1	6.7	4.5	2.0	2.5	6.5	2.3
Fp	.1	.8	2.8	.3	2.5	3.8	1.0	2.5	.5
Fk	1.7	2.0	1.2	3.2	1.5	.3	1.7	.8	1.6
L	.6	4.2	2.0	3.8	2.5	1.0	1.5	1.7	1.6
M				.1					
Py			.2				1.0	1.0	.3
Fbth	1.3	1.1		.2		.8			.1
Fplk	20.5	15.5	1.0	11.0	.5	.3	18.0	2.5	6.8
Glc	1.0	6.0	11.8	9.2	10.5	23.2	4.5	9.7	4.1
Mtx	62.3	42.8	41.6	45.7	37.0	50.0	49.7	43.5	73.9
Other	1.8	<0.1	.1		1.3	.4	1.3	3.0	.1
Cmt			.5						
Q*	80.8	79.6	86.6	78.5	87.2	79.6	83.3	87.6	74.8
F*	14.1	8.3	9.0	10.4	7.9	16.5	10.8	8.1	14.3
L*	5.1	12.1	4.4	11.1	4.9	3.9	5.9	4.4	10.9

	Teredo Limestone (cont)			Additional Lithologies	
Sample	2/9	25/13	Mean	200/1	50/24
Qm	28.0	23.0	22.4	68.8	43.2
Qp	4.8	2.3	4.3	1.2	.7
Fp	3.2	4.2	2.0	3.5	4.1
Fk	1.7	.2	1.4	3.8	2.1
L	2.0	1.3	2.0	4.2	.6
M	.3		.1	3.0	.2
Py		.3	.5	1.0	
Fbth			.5		
Fplk	.2	.5	7.0		1.1
Glc	6.0	14.7	9.2		2.0
Mtx	50.0	53.4	50.0	14.5	
Other	3.8	.1	1.2		2.2
Cmt			.2		43.6
Q*	82.4	81.5	82.0	79.6	86.2
F*	12.6	13.9	11.4	12.8	12.5
L*	5.0	4.6	6.6	7.6	1.3

TABLE IIIc:
Summary of composition of Teredo Limestone in terms of micrite (M), bioclasts (B), glauconite (G), siliciclasts (S). Data calculated from Table IIIb.

Sample	5/1	128/1	122/3	4/5	52/5	43/17	1/2	12/3	20/5
B	62.8	29.2	1.7	20.7	2.0	2.4	38.1	4.8	26.6
G	2.7	10.5	20.8	17.1	16.8	46.6	9.3	18.6	15.9
S	34.5	60.3	77.5	62.3	81.2	51.0	52.6	76.6	57.5
M	63.0	45.6	47.7	50.4	41.6	65.4	53.1	50.4	77.3
B	23.9	17.8	1.3	12.4	1.4	1.5	19.7	2.9	7.2
S	13.1	36.6	51.0	37.2	57.0	33.1	27.2	46.7	15.5
M	62.3	42.9	41.9	44.7	37.2	50.2	48.5	45.3	74.1
B+G	24.7	22.7	13.1	22.3	11.8	24.4	26.6	12.8	11.0
S	13.0	34.4	45.0	33.0	51.0	25.4	24.9	41.9	14.9

Sample	2/9	25/13	Mean	-1 s.d.	+1 s.d.
B	8.0	1.2	18.0	-1.0	36.9
G	12.1	34.9	18.7	6.9	30.4
S	79.9	63.9	63.4	49.5	77.3
M	53.3	66.2	55.8	45.6	66.1
B	4.3	.6	8.5	.3	16.6
S	42.4	33.3	35.7	22.7	48.7
M	50.1	55.9	50.3	40.3	60.3
B+G	10.0	15.9	17.8	11.7	23.8
S	39.9	28.2	32.0	20.4	43.5

TABLE IIId:
Summary of modal composition of Fells Greensand plus suite of sandstone dikes.

Sample	101/1	104/13	104/14	104/17	104/18	105/3	110/5	125/3	128/6
Qm	51.0	44.8	30.5	46.0	45.3	38.8	37.0	43.0	61.8
Qp	6.3	2.2	22.2	4.7	7.8	4.2	1.5	3.8	1.3
Fp	2.0	1.6	.4	.8	.1	.5	.5	1.3	2.0
Fk	2.5	.6	.9	2.2	.5	3.2	.7	3.0	2.5
L		.2	1.1	.5	.1	.2		1.3	.5
M			.1				.3		
Py			.1				.2	.3	
Fbth			.1						
Fplk			.1						
Glc	1.7	5.6	4.0	12.3	2.6	8.2	3.0	3.5	5.5
Mtx									
Other			1.2		.2				
Cmt	37.5	45.0	39.4	33.5	43.5	44.9	56.8	43.8	26.5
Q*	94.2	95.1	95.6	93.5	98.9	91.8	97.1	92.0	92.6
F*	5.8	4.5	2.4	5.5	1.1	7.8	2.9	6.0	6.6
L*	0.0	.4	2.0	.9	0.0	.4	0.0	2.0	.8

	Fells Greensand (cont)			Clastic Dikes			
Sample	50/14	300/2	Mean	300/4	700/2	20/18	Mean
Qm	43.3	42.3	44.0	44.7	43.8	54.5	47.7
Qp	10.5	2.7	6.1	1.8	1.5	2.0	1.8
Fp	.5	1.8	1.0	1.0	2.2	1.5	1.6
Fk	3.2	3.0	2.0	.8	3.0	1.5	1.8
L	.5	.5	.4	1.3	.3	.1	.6
M				.1			.1
Py	1.6		.2	.1	.1		.1
Fbth	.1						
Fplk	.6	.3	.1				
Glc	6.9	13.2	6.0	2.2	4.3	1.5	2.7
Mtx							
Other					.1		.1
Cmt	33.8	36.2	40.1	47.8	44.7	38.2	43.6
Q*	94.1	89.4	94.0	93.6	89.2	91.3	91.4
F*	5.0	9.6	5.2	3.7	10.2	8.7	7.5
L*	.9	1.0	.8	2.7	.6	0.0	1.1

FORMATION WOODSIDE FORMATION
LOCATION Woodside Creek   SAMPLE NO JM 200/1
                                 COLUMN NO JM 104
COLOUR 5 Y 7/2   INDURATION Poorly indtd
STRUCTURES Bouma sequence, carbonaceous laminae

TEXTURE
Mode(s) 85% vcZ (mean:0.06mm; max:0.2mm)
        15% Clay
Rounding Very angular
Sorting Very well sorted

COMPOSITION

Qm	% 68.8	Straight & clean
Qp	1.2	Stretched, finely sutured crystals
Fp	3.5	Fresh albite
Fk	3.8	Altered
L	4.2	Fresh basalt, minor chert
M	3.0	
Py	1.0	
Fbth		
Fplk		
Glc		
Mtx	14.5	Limonitic (tuffaceous?) matrix
Other		
Cmt		

NAME Yellowish grey, poorly indurated, turbiditic, very well sorted, clayey coarse siltstone: micaceous, subfeldsarenite

FORMATION WOOLSHED FORMATION (intercalated sandstone)
LOCATION Flaxbourne River mouth   SAMPLE NO JM 300/8
                                         COLUMN NO
COLOUR 5 GY 6/1   INDURATION Well indurated
STRUCTURES Normal grading

TEXTURE
Mode(s) 76% vfS (mean: 0.07mm; max: 0.12mm)

Rounding Angular
Sorting Very well sorted

COMPOSITION

Qm	% 57.0	Clean. Non-undulose
Qp	2.5	Straight, polygonal crystal boundaries
Fp	1.3	Moderately fresh albite
Fk	5.5	Highly altered. Some fresh microcline
L	4.2	Volcanics, minor chert
M	2.5	
Py		
Fbth		
Fplk		
Glc	3.0	
Mtx		
Other		
Cmt	24.0	Blocky calcite

NAME Greenish grey, well indurated, normally graded, very well sorted, very fine sandstone: blocky calcite cemented, micaceous, glauconitic, subfeldsarenite

FORMATION WOOLSHED FORMATION
LOCATION Branch Stream

SAMPLE NO JM 40/12
COLUMN NO JM 40

COLOUR N7
INDURATION Moderate
STRUCTURES Massive clastic dike

TEXTURE
Mode(s) 81% vfS (mean: 0.1mm; max: 0.21mm)
19% Mud
Rounding Angular - sub angular
Sorting Well sorted

COMPOSITION

Qm	% 59.0	High% undulose
Qp	6.8	
Fp	2.3	Relatively fresh
Fk	9.3	Moderately weathered orthoclase
L	2.5	Chert, basalt
M		
Py		
Fbth		
Fplk		
Glc	1.8	
Mtx	18.5	
Other		
Cmt		

NAME Light grey, moderately indurated, massive, well sorted, muddy, very fine sandstone: glauconitic, sufeldsarenite

FORMATION WOOLSHED FORMATION (interbedded sandstone)
LOCATION Dart Stream

SAMPLE NO JM 10/4
COLUMN NO JM 42

COLOUR 5 YR 6/1
INDURATION Well indurated
STRUCTURES Massive

TEXTURE
Mode(s) 69% vfS (mean: 0.1mm; max: 0.22mm)

Rounding Angular - very angular
Sorting Very well sorted

COMPOSITION

Qm	% 53.5	Straight
Qp	3.8	Finely sutured crystal boundaries
Fp	2.0	Moderately fresh albite
Fk	5.0	Very altered
L	2.0	Chert, altered basalt, siltstone
M		
Py		
Fbth		
Fplk		
Glc	2.8	
Mtx		
Other	0.2	Rare broken teeth
Cmt	30.8	Blocky calcite cement

NAME Light brownish grey, well indurated, massive, very well sorted, very fine sandstone: blocky calcite cemented, glauconitic, subfeldsarenite

FORMATION CLAVERLEY SANDSTONE
LOCATION Kaikoura Peninsula
SAMPLE NO JM 4/2
COLUMN NO JM 23
COLOUR N 7
INDURATION Well indurated
STRUCTURES 10cm-bedded, internally bioturbated

TEXTURE
Mode(s) 43% vfS (mean: 0.07mm; max: 0.17mm)
57% Mud
Rounding Very angular
Sorting Well sorted

COMPOSITION

Qm %	25.0	Straight
Qp	4.4	Sutured crystal boundaries
Fp	1.9	Fresh albite
Fk	2.4	
L	0.5	Basalt
M	0.5	
Py	0.1	
Fbth	0.9	Thick walled, calcareous
Fplk	2.1	
Glc	4.1	Mean size 0.15mm
Mtx	57.3	Clay (30%), micrite (22.5%) in separate patches
Other	0.7	Large sponge spicules, molluscan fragments, Ph
Cmt		

NAME Light medium grey, well indurated, 10cm-bedded, well sorted, very fine sandy, mudstone: micritic, fossiliferous, glauconitic, subfeldsarenite

FORMATION CLAVERLEY SANDSTONE
LOCATION Kaikoura Peninsula
SAMPLE NO JM 4/1
COLUMN NO JM 4
COLOUR 10 GY 5/2 - 5 G 5/2
INDURATION Well indurated
STRUCTURES Nodular 10cm-bedded

TEXTURE
Mode(s) 50% vfS (mean: 0.09mm; max: 0.15mm)
50% Mud
Rounding Angular
Sorting Well sorted

COMPOSITION

Qm %	30.0	Straight
Qp	3.1	
Fp	1.5	Albite
Fk	1.0	Orthoclase, rare microcline
L	0.1	Schist
M	0.1	
Py	0.2	
Fbth	0.7	Very thick-walled, calcareous
Fplk	0.3	
Glc	11.1	
Mtx	50.6	
Other	1.3	Large sponge spicules, Ph grains, echinoid frags
Cmt		

NAME Light medium greyish green, well indurated, 10cm-bedded, well sorted, muddy, very fine sandstone: micritic, glauconitic, subfeldsarenite

FORMATION CLAVERLEY SANDSTONE
LOCATION Conway River Mouth SAMPLE NO JM 6/4
COLUMN NO JM 6
COLOUR 5 G 8/1 INDURATION Moderate
STRUCTURES Massive

TEXTURE
Mode(s) 90% fS (mean: 0.2mm; max: 0.3mm)
10% Mud
Rounding Angular
Sorting Very well sorted

COMPOSITION

Qm	% 54.6	Straight
Qp	21.7	Fine grained, sutured crystals
Fp	2.3	
Fk	5.2	
L	3.5	Chert (2.5%), basalt (0.5%), siltstone (0.5%)
M	0.2	
Py	0.3	
Fbth		
Fplk		
Glc	1.5	
Mtx	10.5	
Other		
Cmt		

NAME Light greenish grey, moderately indurated, massive, very well sorted, fine sandstone: glauconitic, subfeldsarenite

FORMATION CLAVERLEY SANDSTONE
LOCATION Puhi Puhi River SAMPLE NO JM 25/7
COLUMN NO JM 25
COLOUR N 6 INDURATION Well indurated
STRUCTURES Massive, intensely bioturbated

TEXTURE
Mode(s) 80% vfS (mean: 0.1mm; max: 0.3mm)
9% Mud
Rounding Angular
Sorting Very well sorted

COMPOSITION

Qm	% 47.3	High% undulose
Qp	18.7	Straight crystal boundaries
Fp	2.3	Albite
Fk	5.0	
L	3.5	Basalt with some chert
M	1.2	
Py	0.2	
Fbth		
Fplk		
Glc	0.8	
Mtx	9.0	
Other	0.1	Echinoid fragments
Cmt	12.2	Sparry calcite

NAME Medium light grey, well indurated, massive, very well sorted, very fine sandstone: sparry calcite cemented, subfeldsarenite

FORMATION CLAVERLEY SANDSTONE
LOCATION Mt Alexander
SAMPLE NO JM 18/6
COLUMN NO JM 18
COLOUR 5 YR 8/1
INDURATION Well indurated
STRUCTURES Massive

TEXTURE
Mode(s) 54% fS (mean: 0.2mm; max: 0.3mm)
46% Mud
Rounding Angular
Sorting Very well sorted

COMPOSITION

	%	
Qm	32.5	>50% undulose extinction
Qp	6.1	Fine grained, sutured crystal boundaries
Fp	3.5	Fresh albite
Fk	2.0	Orthoclase, minor microcline
L	3.2	Basalt (2%), chert (0.8%), siltstone (0.4%)
M		
Py		
Fbth	0.2	Large, calcareous
Fplk	1.9	
Glc	4.0	
Mtx	46.0	Micrite
Other	0.1	Echinoid fragments
Cmt		

NAME Light pinkish grey, well indurated, massive, very well sorted, muddy, fine sandstone: glauconitic, micritic, subfeldsarenite

FORMATION CLAVERLEY SANDSTONE
LOCATION Dart Stream
SAMPLE NO JM 10/3
COLUMN NO JM 10
COLOUR 5 YR 6/1
INDURATION Well indurated
STRUCTURES Massive

TEXTURE
Mode(s) 77% fS (mean: 0.13mm; max: 0.2mm)
15% Mud
Rounding Very angular
Sorting Well sorted

COMPOSITION

	%	
Qm	46.3	Straight
Qp	13.7	Finely sutured
Fp	3.3	Albite
Fk	5.0	Orthoclase
L	2.0	Chert, minor basalt, rare schist
M	1.1	
Py	0.6	
Fbth		
Fplk		
Glc	0.5	
Mtx	14.5	
Other		
Cmt	13.0	Sparry calcite

NAME Light brownish grey, well indurated, massive, well sorted, muddy, fine sandstone: calcite cemented, subfeldsarenite

FORMATION CLAVERLEY SANDSTONE
LOCATION Bluff Stream SAMPLE NO JM 12/1
COLUMN NO JM 50 B
COLOUR 5 YR 6/1 INDURATION Moderate
STRUCTURES Massive with indistinct laminations showing large-scale convolutions and flame structures
TEXTURE
Mode(s) 72% vfS (mean: 0.1mm; max: 0.15mm)

Rounding Very angular
Sorting Well sorted

COMPOSITION

Qm %	38.5	Straight
Qp	17.0	Unsutured equant crystals
Fp	5.0	Fresh albite
Fk	5.3	Altered orthoclase
L	4.0	Chert
M	1.0	
Py	0.5	
Fbth		
Fplk		
Glc	0.5	
Mtx		
Other		
Cmt	28.2	Sparry calcite

NAME Light brownish grey, moderately indurated, massive, well sorted, very fine sandstone: calcite cemented, subfeldsarenite

FORMATION CLAVERLEY SANDSTONE
LOCATION Puhi Puhi River SAMPLE NO JM 25/8
COLUMN NO JM 25
COLOUR 5 GY 4/1 INDURATION Moderate
STRUCTURES 10cm-bedded

TEXTURE
Mode(s) 48% vfS (mean: 0.1mm; max: 0.2mm)
52% Mud
Rounding Very angular
Sorting Well sorted

COMPOSITION

Qm %	33.7	Straight
Qp	2.8	Finely sutured crystal boundaries
Fp	2.0	Albite
Fk	2.8	Orthoclase
L	1.0	Chert, siltstone, myrmekite
M	1.2	
Py	0.5	
Fbth	0.5	Large, thick walled, calcareous
Fplk	2.2	
Glc	1.0	
Mtx	51.8	Muddy micrite
Other	0.5	Echinoid fragments
Cmt		

NAME Dark greenish grey, moderately indurated, 10cm-bedded, well sorted, very fine sandy, mudstone: micritic, foraminiferal, subfeldsarenite

FORMATION MEAD HILL FORMATION (intercalated sandstone)
LOCATION Swale Stream SAMPLE NO JM SS1
COLUMN NO
COLOUR 5 YR 6/1 INDURATION Well indurated
STRUCTURES Laminated

TEXTURE
Mode(s) 71% vfS (mean: 0.09mm;max: 0.2mm)
7% Mud
Rounding Angular
Sorting Well sorted

COMPOSITION

Qm %	52.7	Straight. Clean
Qp	5.2	Straight crystal boundaries
Fp	1.8	Very altered albite
Fk	4.0	Very altered
L	3.2	Basalt, chert
M	2.2	
Py		
Fbth		
Fplk		
Glc	0.8	
Mtx	7.3	Clay rich in silt size mica
Other		
Cmt	22.0	Blocky calcite

NAME Light brownish grey, well indurated, laminated, well sorted, muddy, very fine sandstone: blocky calcite cemented, micaceous subfeldsarenite

FORMATION FLAXBOURNE LIMESTONE (intercalated sandstone)
LOCATION Flaxbourne River mouth SAMPLE NO JM 300/6
COLUMN NO
COLOUR INDURATION Very well indtd
STRUCTURES Normal grading, burrowed

TEXTURE
Mode(s) 65% fS (mean: 0.21mm; max: 0.5mm)

Rounding Sub rounded - sub angular
Sorting Well sorted

COMPOSITION

Qm %	46.8	Straight. Abundant inclusion trails
Qp	7.0	Sutured crystal boundaries
Fp	1.7	Moderately weathered albite
Fk	2.2	
L	3.8	Siltstone, chert
M		
Py		
Fbth		
Fplk	<0.1	Thick shelled, calcareous
Glc	1.2	
Mtx		
Other	2.1	?Mdst rip-ups, well rounded. May be lithic fragments
Cmt	35.2	Large (<10mm) blocky calcite

NAME Medium bluish grey, very well indurated, normally graded, well sorted, fine sandstone: blocky calcite cemented, glauconitic, sublitharenite

FORMATION TEREDO LIMESTONE
LOCATION Kaikoura Peninsula SAMPLE NO JM 1/2
COLUMN NO JM 1
COLOUR N 8 INDURATION Moderate
STRUCTURES Massive, intensely bioturbated

TEXTURE
Mode(s) 1. Glc:5% fS (0.2mm) 2. D:27% fS (mean: 0.18mm; max: 0.45mm) 3. F:18% vfS (0.1mm) 4. 50% Mud
Rounding Very angular detritals
Sorting Well sorted modes

COMPOSITION

Qm %	18.8	Straight
Qp	2.5	Unsutured
Fp	1.0	Fresh albite
Fk	1.7	Moderately weathered orthoclase
L	1.5	Chert & rare schist
M		
Py	1.0	
Fbth		
Fplk	18.0	
Glc	4.5	
Mtx	49.7	Micrite
Other	1.3	Echinoid, Ph, molluscan fragments
Cmt		

NAME Very light grey, moderately indurated, massive, well sorted, bimodal, very fine and fine sandy, packstone: subfeldsarenitic, glauconitic, foraminiferal biomicrite

FORMATION TEREDO LIMESTONE
LOCATION Bluff Stream SAMPLE NO JM 12/3
COLUMN NO JM 50 A
COLOUR 5 G 8/1 INDURATION Well indurated
STRUCTURES 15cm bedded, intensely bioturbated

TEXTURE
Mode(s) 1. Glc:10% fS (0.15mm) 2. D:40% vfS (mean: 0.1mm; max: 0.4mm) 3. 44% Mud
Rounding Very angular detritals
Sorting Well sorted modes

COMPOSITION

Qm %	28.7	Straight
Qp	6.5	
Fp	2.5	Fresh albite
Fk	0.8	Fresh orthoclase, rare fresh microcline
L	1.7	Chert
M		
Py	1.0	
Fbth		
Fplk	2.5	
Glc	9.7	
Mtx	43.5	Micrite
Other	3.0	Phosphatic micrite fragments ($\lesssim$ vcS)
Cmt		

NAME Light greenish grey, well indurated, 15cm-bedded, well sorted, bimodal,very fine and fine sandy, mudstone: subfeldsarenitic, glauconitic, foraminiferal micrite

FORMATION TEREDO LIMESTONE
LOCATION Bluff River SAMPLE NO JM 52/5
COLUMN NO JM 52
COLOUR 10 Y 6/2 INDURATION Moderate
STRUCTURES Massive

TEXTURE
Mode(s) 1. Glc:11% fS (0.2mm) 2. D:51% vfS (mean: 0.1mm; max: 0.4mm) 3. 37% Mud
Rounding Angular detritals
Sorting Very well sorted modes

COMPOSITION

Qm	% 39.8	Straight
Qp	4.5	Some sutured
Fp	2.5	Albite
Fk	1.5	Orthoclase, minor perthite
L	2.5	Quartzite?, siltstone, chert, basalt
M		
Py		
Fbth		
Fplk	0.5	
Glc	10.5	
Mtx	37.0	Micrite
Other	1.3	Echinoid & (algal-bored) phosphatic fragments
Cmt		

NAME Pale olive, moderately indurated, massive, very well sorted, muddy, very fine sandstone: micritic, glauconitic, subfeldsarenite

FORMATION TEREDO LIMESTONE
LOCATION Muzzle Stream SAMPLE NO JM 43/17
COLUMN NO JM 43
COLOUR 10 GY 5/2 INDURATION Moderate
STRUCTURES Massive. Glauconite normally graded

TEXTURE
Mode(s) 1. Glc:23% fS (0.2mm) 2. D:25% vfS (mean: 0.1mm; max: 0.5mm) 3. 50% Mud
Rounding Very angular detritals
Sorting Well sorted modes

COMPOSITION

Qm	% 18.2	Straight
Qp	2.0	
Fp	3.8	Fresh albite
Fk	0.3	
L	1.0	Chert
M		
Py		
Fbth	0.8	
Fplk	0.3	Mostly broken tests
Glc	23.2	
Mtx	50.0	Micrite
Other	0.4	Ph fragments, teeth, ech spines, sponge spicules
Cmt		

NAME Greyish green, moderately indurated, massive, well sorted, very fine sandy, mudstone: subfeldsarenitic, glauconitic micrite

FORMATION TEREDO LIMESTONE
LOCATION Seymour Stream   SAMPLE NO JM 122/3
COLUMN NO JM 120
COLOUR 5 G 6/1   INDURATION Poor
STRUCTURES Massive

TEXTURE
Mode(s) 57% fS (mean: 0.2mm; max: 0.5mm)
42% Mud
Rounding Angular detritals
Sorting Well sorted modes

COMPOSITION

Qm	% 33.9	Straight
Qp	5.1	Sutured crystal boundaries
Fp	2.8	
Fk	1.2	
L	2.0	Chert & minor siltstone
M		
Py	0.2	
Fbth		
Fplk	1.0	Very poorly preserved
Glc	11.8	Some with foram shell surrounding
Mtx	41.6	Micrite
Other	0.1	Echinoid fragments
Cmt	0.5	Sparry calcite

NAME Greenish grey, poorly indurated, massive, well sorted, muddy, very fine sandstone: micritic, glauconitic, subfeldsarenite

FORMATION TEREDO LIMESTONE
LOCATION Kaikoura Peninsula   SAMPLE NO JM 4/5
COLUMN NO JM 23
COLOUR N 8   INDURATION Well indurated
STRUCTURES Massive, intensely bioturbated

TEXTURE
Mode(s) 1. Glc:9% mS (0.3mm) 2. D:34% fS (mean: 0.2mm; max: 0.5mm) 3. F:11% fS (0.2mm) 4. 46% Mud
Rounding Angular detritals
Sorting Well sorted modes

COMPOSITION

Qm	% 19.8	Straight
Qp	6.7	Sutured crystal boundaries
Fp	0.3	Fresh albite
Fk	3.2	Orthoclase
L	3.8	Chert
M	0.1	
Py		
Fbth	0.2	
Fplk	11.0	Unbroken tests
Glc	9.2	
Mtx	45.7	Micrite
Other		
Cmt		

NAME Very light grey, moderately indurated, massive, well sorted, fine sandy, packstone: sublitharenitic, glauconitic, foraminiferal biomicrite

FORMATION TEREDO LIMESTONE
LOCATION Haumuri Bluff

SAMPLE NO JM 5/1
COLUMN NO JM 15

COLOUR 10 YR 5/4
INDURATION Very well indtd
STRUCTURES Massive, intensely burrowed

TEXTURE

Mode(s) 1. D:13% fS (mean: 0.17mm; max: 0.3mm) 2. F:22% fS (0.13mm) 3. 62% Mud
Rounding Angular detritals
Sorting Well sorted modes

COMPOSITION

	%	
Qm	6.3	Straight
Qp	4.2	Unsutured crystal boundaries
Fp	0.1	Very angular, fresh, albite & An45-An85
Fk	1.7	Orthoclase, some microcline
L	0.6	Moderately weathered basalt & minor chert
M		
Py		
Fbth	1.3	
Fplk	20.5	Unbroken Globigerinids with micritic infillings
Glc	1.0	
Mtx	62.3	Micrite
Other	1.8	Echinoid & molluscan fragments, teeth
Cmt		

NAME Moderate yellowish brown, very well indurated, massive, well sorted, fine sandy, wackestone: subfeldsarenitic, glauconitic, foraminiferal biomicrite

FORMATION TEREDO LIMESTONE
LOCATION Limestone Hill

SAMPLE NO JM 128/1
COLUMN NO JM 128

COLOUR 5 Y 8/4
INDURATION Moderate
STRUCTURES Massive

TEXTURE

Mode(s) 1. Glc:6% fS (0.2mm) 2. D:34% fS (mean: 0.18mm; max: 0.35mm) 3. F:17% vfS (0.1mm) 4. 43% Mud
Rounding Angular detritals
Sorting Well sorted modes

COMPOSITION

	%	
Qm	21.3	Straight
Qp	6.0	Unsutured crystal boundaries
Fp	0.8	Albite
Fk	2.0	Orthoclase, minor microcline
L	4.2	Chert
M		
Py		
Fbth	1.1	
Fplk	15.5	Unbroken tests
Glc	6.0	
Mtx	42.8	Micrite
Other	<0.1	Teeth
Cmt		

NAME Greyish yellow, moderately indurated, massive, well sorted, bimodal, very fine and fine sandy, wackestone: sublitharenitic, glauconitic, foraminiferal biomicrite

FORMATION TEREDO LIMESTONE
LOCATION Puhi Puhi River
SAMPLE NO JM 20/5
COLUMN NO JM 20
COLOUR 5 Y 6/1
INDURATION Well indurated
STRUCTURES 10-50cm bedded

TEXTURE
Mode(s) 1. Glc:4% fS (0.15mm) 2. D:15% vfS (mean: 0.1mm; max: 0.13mm) 3. F:7% vfS (0.1mm) 4. 74% Mud
Rounding Very angular detritals
Sorting Well sorted modes

COMPOSITION

Qm %	8.8	Straight
Qp	2.3	
Fp	0.5	Albite
Fk	1.6	Orthoclase
L	1.6	Chert
M		
Py	0.3	
Fbth	0.1	
Fplk	6.8	Unbroken tests
Glc	4.1	
Mtx	73.9	Micrite
Other	0.1	Sponge spicules (≤ 0.2mm diameter) & rare teeth
Cmt		

NAME Light olive grey, well indurated, 10-50cm bedded, well sorted, very fine sandy, mudstone: lithic feldsarenitic, glauconitic, foraminiferal micrite

FORMATION TEREDO LIMESTONE
LOCATION Kaikoura Peninsula
SAMPLE NO JM 2/9
COLUMN NO JM 2
COLOUR 5 G 5/2
INDURATION Moderate
STRUCTURES Massive, intensely bioturbated

TEXTURE
Mode(s) 1. 50% vfS (mean: 0.08mm; max: 0.25mm)
2. 50% Mud
Rounding Very angular detritals
Sorting Well sorted modes

COMPOSITION

Qm %	28.0	Straight
Qp	4.8	
Fp	3.2	Fresh albite
Fk	1.7	
L	2.0	Chert
M	0.3	
Py		
Fbth		
Fplk	0.2	
Glc	6.0	
Mtx	50.0	Micrite
Other	3.8	Sponge spicules (≤ 0.2mm diameter)
Cmt		

NAME Greyish green, moderately, massive, moderately sorted, very fine sandy, mudstone: subfeldsarenitic, glauconitic, spicular micrite

FORMATION TEREDO LIMESTONE
LOCATION Puhi Puhi River SAMPLE NO JM 25/13
COLUMN NO JM 25
COLOUR 5 G 4/1 INDURATION Very well indtd
STRUCTURES Massive

TEXTURE
Mode(s) 1. Glc:15% fS (0.14mm) 2. D:31% vfS (mean: 0.07mm; max: 0.2mm) 3. 53% Mud
Rounding Very angular detritals
Sorting Moderately sorted

COMPOSITION

Qm %	23.0	Straight
Qp	2.3	
Fp	4.2	Fresh albite
Fk	0.2	
L	1.3	Chert
M		
Py	0.3	
Fbth		
Fplk	0.5	
Glc	14.7	
Mtx	53.4	Micrite
Other	0.1	Echinoid spines & Ph fragments
Cmt		

NAME Dark greenish grey, very well indurated, massive, well sorted, bimodal, very fine and fine sandy, mudstone: subfeldsarenitic, glauconitic, micrite

FORMATION FELLS GREENSAND
LOCATION Kekerengu River SAMPLE NO JM 101/1
COLUMN NO JM 101
COLOUR 5 G 8/1 INDURATION Moderate
STRUCTURES Massive

TEXTURE
Mode(s) 63% fS (mean: 0.2mm; max: 0.3mm)

Rounding Angular
Sorting Well sorted

COMPOSITION

Qm %	51.0	High% undulose
Qp	6.3	Complexly sutured crystal boundaries
Fp	2.0	Albite
Fk	2.5	Very fresh microcline & some orthoclase
L		
M		
Py		
Fbth		
Fplk		
Glc	1.7	Well rounded (0.18mm)
Mtx		
Other		
Cmt	37.5	Sparry calcite

NAME Light greenish grey, moderately indurated, massive, well sorted, fine sandstone: sparry calcite cemented, glauconitic, subfeldsarenite

FORMATION Sandstone underlying Grasseed Volcanics
LOCATION Bluff Stream (lower)
SAMPLE NO JM 50/24
COLUMN NO JM 50 A
COLOUR 5 G 8/1
INDURATION Moderate
STRUCTURES Massive

TEXTURE
Mode(s) 56% vfS (mean:0.1mm; max: 0.15mm)

Rounding Very angular
Sorting Very well sorted

COMPOSITION

Qm %	43.2	Straight, some undulose
Qp	0.7	
Fp	4.1	Fresh albite
Fk	2.1	
L	0.6	Chert & siltstone
M	0.2	
Py		
Fbth		
Fplk	1.1	
Glc	2.0	
Mtx		
Other	2.2	Foraminiferal biomicrite rip-ups (2%) & Ph grains
Cmt	43.6	Microspar

NAME Light greenish grey, moderately indurated, massive, very well sorted, very fine sandstone: calcite cemented, glauconitic, intraclastic, subfeldsarenite

FORMATION FELLS GREENSAND
LOCATION Woodside Creek
SAMPLE NO JM 104/14
COLUMN NO JM 104
COLOUR 10 GY 5/2
INDURATION Well indurated
STRUCTURES Massive

TEXTURE
Mode(s) 1. 50% cS (mean: 0.8mm; max: 1.8mm)
2. 10% vfS (mean: 0.09mm; max: 0.11mm)
Rounding 1. Very well rounded 2. Very angular
Sorting 1. Well sorted 2. Very well sorted

COMPOSITION

Qm %	30.5	Straight
Qp	22.2	Straight, stretched crystal boundaries
Fp	0.4	Fresh albite
Fk	0.9	Fresh orthoclase & microcline
L	1.1	Basalt & chert
M	0.1	
Py	0.1	
Fbth	0.1	Agglutinated 0.25mm diameter
Fplk	0.1	
Glc	4.0	Bimodal (0.5mm & 0.08mm), well sorted modes
Mtx		
Other	1.2	Foraminiferal biomicrite rip-ups & Ph fragments
Cmt	39.4	Blocky & void filling drusy, sparry calcite

NAME Greyish green, well indurated, massive, well sorted, bimodal, very fine and coarse sandstone: sparry calcite cemented, glauconitic, intraclastic, quartzarenite

FORMATION FELLS GREENSAND
LOCATION Bluff Stream (upper) SAMPLE NO JM 50/14
COLUMN NO JM 50 B
COLOUR 5 G 6/1 INDURATION Well indurated
STRUCTURES Massive. 0.03mm chert veinlets

TEXTURE
Mode(s) 1. 60% mS (0.3mm)
2. 6% vfS (0.1mm)
Rounding 1. Sub rounded 2. Angular to very angular
Sorting Well sorted modes

COMPOSITION

Qm %	43.3	mS: undulose; vfS: straight
Qp	10.5	Moderately sutured crystal boundaries
Fp	0.5	Fresh albite
Fk	3.2	Fresh microcline & perthite
L	0.5	Chert or quartzite
M		
Py	1.6	0.05 - 0.1mm
Fbth	0.1	Very poorly preserved
Fplk	0.6	Very poorly preserved
Glc	6.9	Poorly sorted
Mtx		
Other		
Cmt	33.8	Blocky (1.5mm) sparry calcite

NAME Greenish grey, well indurated, massive, well sorted, bimodal, very fine and medium sandstone: sparry calcite cemented, glauconitic, subfeldsarenite

FORMATION FELLS GREENSAND
LOCATION Woodside Creek SAMPLE NO JM 104/13
COLUMN NO JM 104
COLOUR 5 G 6/1 INDURATION Very well indtd
STRUCTURES Indistinct laminations. Ungraded

TEXTURE
Mode(s) 55% fS (0.15mm)

Rounding Very angular
Sorting Very well sorted

COMPOSITION

Qm %	44.8	Straight
Qp	2.2	Sutured crystal boundaries
Fp	1.6	Very fresh albite
Fk	0.6	Fresh microcline
L	0.2	Chert
M		
Py		
Fbth		
Fplk		
Glc	5.6	Well rounded (0.15mm)
Mtx		
Other		
Cmt	45.0	Sparry calcite

NAME Greenish grey, very well indurated, laminated, very well sorted, fine sandstone: sparry calcite cemented, glauconitic, quartzarenite

FORMATION FELLS GREENSAND
LOCATION Woodside Creek SAMPLE NO JM 104/18
COLUMN NO JM 104
COLOUR 5 GY 6/1 - 5 G 6/1 INDURATION Well indurated
STRUCTURES Normal grading. Sharp contact between cS layer below and vfS layer above. Chert veinlets.
TEXTURE
Mode(s) 1. 50% cS (mean: 0.6mm; max: 1.2mm)
2. 7% vfS (mean: 0.08mm; max: 0.15mm)
Rounding 1. Very well rounded 2. Very angular
Sorting 1. Well sorted 2. Very well sorted

COMPOSITION

	%	
Qm	45.3	Straight. Abundant inclusion trails
Qp	7.8	Stretched & sutured crystal boundaries
Fp	0.1	Fresh albite
Fk	0.5	Very fresh orthoclase, perthite, microcline
L	<0.1	Myrmekite
M		
Py		
Fbth		
Fplk		
Glc	2.6	Moderately sorted, well rounded (0.3mm)
Mtx		
Other	0.2	Rounded Ph grains
Cmt	43.5	Blocky, sparry calcite. Some microspar.

NAME Greenish grey, well indurated, normally graded, well sorted, bimodal, very fine and coarse sandstone: sparry calcite cemented, glauconitic, quartzarenite

FORMATION FELLS GREENSAND
LOCATION Deep Creek SAMPLE NO JM 105/3
COLUMN NO JM 105
COLOUR 5 G 6/1 INDURATION Well indurated
STRUCTURES Indistinct laminae (concentrations of glauconite). Normal grading
TEXTURE
Mode(s) 1. 53% fS (mean: 0.18mm; max: 0.4mm)
2. 2% vcS
Rounding 1. Sub angular 2. Very well rounded
Sorting Moderately sorted

COMPOSITION

	%	
Qm	38.8	Straight. Some inclusion trails
Qp	4.2	Straight, polygonal crystal boundaries
Fp	0.5	Fresh albite
Fk	3.2	Fresh orthoclase & microcline
L	0.2	Chert, myrmekite, granite
M		
Py		
Fbth		
Fplk		
Glc	8.2	
Mtx		
Other		
Cmt	44.9	Sparry calcite

NAME Greenish grey, well indurated, laminated, moderately sorted, fine sandstone: sparry calcite cemented, glauconitic, subfeldsarenite

FORMATION FELLS GREENSAND
LOCATION Woodside Creek SAMPLE NO JM 104/17
COLUMN NO JM 104
COLOUR 5 G 4/1 INDURATION Well indurated
STRUCTURES Laminated, normally graded, fluted base.

TEXTURE
Mode(s) 1. 60% mS (0.3mm)
2. 4% m-cZ
Rounding 1. Rounded to sub-rounded 2. Very angular
Sorting 1. Very well sorted 2. Moderately sorted

COMPOSITION

Qm	% 46.0	Straight. Some undulose
Qp	4.7	Straight crystal boundaries
Fp	0.8	Fresh albite
Fk	2.2	Moderately altered orthoclase & microcline
L	0.5	Chert & granite
M		
Py		
Fbth		
Fplk		
Glc	12.3	Well rounded (0.25mm)
Mtx		
Other		
Cmt	33.5	Sparry calcite

NAME Dark greenish grey, well indurated, laminated, very well sorted, bimodal, coarse silty & medium sandstone: sparry calcite cemented, glauconitic, subfeldsarenite

FORMATION Sandstone from flysch facies of WOOLSHED FORMATION
LOCATION Woodside Creek SAMPLE NO JM 704/1
COLUMN NO
COLOUR 5 Y 8/1 INDURATION Moderate
STRUCTURES Bouma sequence

TEXTURE
Mode(s) 96% vfS (mean:0.1mm; max:0.3mm)

Rounding Angular
Sorting Very well sorted

COMPOSITION

Qm	% 69.0	High% undulose
Qp	5.0	Straight, polygonal crystal boundaries
Fp	6.0	Some fresh but mostly very altered albite
Fk	4.5	Very altered
L	12.5	Chert, basalt
M		
Py	1.1	
Fbth		
Fplk		
Glc		
Mtx		
Other	1.9	Carbonaceous material
Cmt	3.5	?Dolomite. Rare 0.3mm rhombs

NAME Yellowish grey, moderately indurated, turbiditic, very well sorted, very fine sandstone: dolomite cemented, carbonaceous, sublitharenite

FORMATION FELLS GREENSAND
LOCATION Blue Mountain Stream

SAMPLE NO JM 110/5
COLUMN NO JM 110
INDURATION Well indurated

COLOUR 5 G 6/1
STRUCTURES Massive

TEXTURE
Mode(s) 43% vfS (mean: 0.1mm; max: 0.2mm)

Rounding Angular to very angular
Sorting Moderately sorted

COMPOSITION

	%	
Qm	37.0	Straight
Qp	1.5	
Fp	0.5	Fresh albite
Fk	0.7	Fresh microcline
L		
M	0.3	
Py	0.2	
Fbth		
Fplk		
Glc	3.0	Well rounded (0.1mm)
Mtx		
Other		
Cmt	56.8	Sparry calcite

NAME Greenish grey, well indurated, massive, moderately sorted, very fine sandstone: sparry calcite cemented, glauconitic, quartzarenite

FORMATION FELLS GREENSAND
LOCATION Limestone Hill

SAMPLE NO JM 128/6
COLUMN NO JM 128
INDURATION Moderate

COLOUR 5 G 8/1
STRUCTURES Massive

TEXTURE
Mode(s) 74% vfS (mean: 0.09mm; max: 0.4mm)

Rounding Sub angular
Sorting Moderately sorted

COMPOSITION

	%	
Qm	61.8	Straight
Qp	1.3	Straight, unstretched crystal boundaries
Fp	2.0	Fresh albite
Fk	2.5	Fresh microcline
L	0.5	Chert
M		
Py		
Fbth		
Fplk		
Glc	5.5	
Mtx		
Other		
Cmt	26.5	Blocky, sparry calcite

NAME Light greenish grey, moderately indurated, massive, moderately sorted, very fine sandstone: sparry calcite cemented, glauconitic, subfeldsarenite

FORMATION FELLS GREENSAND
LOCATION Wallow Creek
SAMPLE NO JM 125/3
COLUMN NO JM 125
COLOUR N 7
INDURATION Moderate
STRUCTURES Massive

TEXTURE
Mode(s) 56% vfS (mean: 0.1mm; max: 0.4mm)

Rounding Angular
Sorting Very well sorted

COMPOSITION

Qm	% 43.0	Straight
Qp	3.8	
Fp	1.3	Fresh albite
Fk	3.0	Fresh microcline & altered orthoclase
L	1.3	Rounded chert
M		
Py	0.3	
Fbth		
Fplk		
Glc	3.5	Well sorted, well rounded (0.1 mm)
Mtx		
Other		
Cmt	43.8	Blocky, sparry calcite

NAME Light grey, moderately indurated, massive, very well sorted, very fine sandstone: sparry calcite cemented, glauconitic, subfeldsarenite

FORMATION DIKE intruding Middle Limestone
LOCATION Puhi Puhi River
SAMPLE NO JM 20/18
COLUMN NO JM 20
COLOUR 5 Y 6/1
INDURATION Moderate
STRUCTURES Massive clastic dike

TEXTURE
Mode(s) 62% fS (mean: 0.15mm; max: 0.5mm)

Rounding Very angular
Sorting Poorly sorted

COMPOSITION

Qm	% 54.5	Straight
Qp	2.0	Unsutured crystal boundaries
Fp	1.5	Fresh albite
Fk	1.5	Fresh microcline
L	<0.1	Rounded chert
M		
Py		
Fbth		
Fplk		
Glc	1.5	
Mtx		
Other		
Cmt	38.2	Blocky, sparry calcite

NAME Light olive grey, moderately indurated, massive, poorly sorted, fine sandstone: sparry calcite cemented, glauconitic, subfeldsarenite

FORMATION DIKE intruding Lower Limestone
LOCATION Needles Point SAMPLE NO JM 300/4
COLUMN NO
COLOUR 5 GY 8/1 INDURATION Well indurated
STRUCTURES Massive clastic dike

TEXTURE
Mode(s) 52% vfS (mean: 0.09mm; max: 0.18mm)

Rounding Sub angular - angular
Sorting Very well sorted

COMPOSITION

Qm %	44.7	Clean. Mostly straight
Qp	1.8	Straight crystal boundaries
Fp	1.0	Very fresh albite
Fk	0.8	Very altered
L	1.3	Basalt and chert
M	0.1	
Py	0.1	
Fbth		
Fplk		
Glc	2.2	
Mtx		
Other		
Cmt	47.8	Blocky calcite cement

NAME Light greenish grey, well indurated, massive, very well sorted, very fine sandstone: blocky calcite cemented, glauconitic, subfeldsarenite

FORMATION DIKE intruding Lower and Upper Marl
LOCATION Mt Alexander SAMPLE NO JM 700/2
COLUMN NO JM 18
COLOUR 5 Y 6/1 INDURATION Well indurated
STRUCTURES Massive clastic dike

TEXTURE
Mode(s) 1. 41% fS (mean: 0.15mm)
2. 14% mS (mean: 0.40mm)
Rounding 1. Sub angular - sub rounded 2. Rounded
Sorting Very well sorted modes

COMPOSITION

Qm %	43.8	Straight. Some inclusion trails
Qp	1.5	Large equant crystals with straight boundaries
Fp	2.2	Moderately fresh albite
Fk	3.0	Some fresh microcline
L	0.3	Chert
M		
Py	<0.1	
Fbth		
Fplk		
Glc	4.3	
Mtx		
Other	<0.1	Pyritized radiolaria
Cmt	44.7	Blocky calcite

NAME Light olive grey, well indurated, massive, very well sorted, bimodal, fine and medium sandstone: blocky calcite cemented, glauconitic, subfeldsarenite

FORMATION FELLS GREENSAND
LOCATION Marfells Beach SAMPLE NO JM 300/2
COLUMN NO
COLOUR 5 G 5/2 INDURATION Very well indtd
STRUCTURES Hummocky cross-stratified, lensoidal, normally graded, burrowed, loaded flute casts and burrows
TEXTURE
Mode(s) 74% vfS - fS (mean: 0.12mm; max: 0.35mm)

Rounding Sub angular
Sorting Very well sorted

COMPOSITION

Qm %	42.3	Straight
Qp	2.7	Sutured crystal boundaries
Fp	1.8	Fresh albite
Fk	3.0	Moderately altered orthoclase, rare fresh microcline
L	0.5	Altered basalt, very rare chert
M		
Py		
Fbth	<0.1	Small biserials with pyritized chambers
Fplk	0.3	Very poorly preserved but unbroken
Glc	13.2	
Mtx		
Other		
Cmt	36.2	Blocky calcite

NAME Greyish green, very well indurated, hummocky cross-stratified, bioturbated, very well sorted, fine sandstone: calcite cemented, glauconitic, quartzarenite

APPENDIX IV: Key Measured Sections

COLUMN NO.	LOCATION	NZMS 1	GRID REFERENCE Bottom	Top
JM 1	Kaikoura Peninsula	S49	963888	968885
JM 2	Kaikoura Peninsula	S49	983899	983899
JM 3	Oaro	S56	802773	802775
JM 4	Kaikoura Peninsula	S49	978898	978897
JM 6	Conway River Mouth	S55	756668	756668
JM 7	Cribb Creek	S49	806942	805943
JM 15	Haumuri Bluff	S56	821773	812732
JM 18	Mt Alexander	S42	073157	072158
JM 19	Mororimu Stream	S42	137134	144137
JM 20	Puhi Puhi River	S49	020070	021071
JM 25	Puhi Puhi River	S42	036109	035105
JM 26	Clinton Stream	S49	018077	018077
JM 30	Mead Stream	S35	087451	075452
JM 31	Limburn Stream	S35	064426	061427
JM 32	Dee Stream	S42(35)	027398	022041
JM 40A	Branch Stream	S42	012380	011381
JM 40B	Branch Stream	S42	008375	006378
JM 41	Whisky Stream	S42	997362	995363
JM 42	Dart Stream	S42	973340	966342
JM 43A	Dead Horse Gully	S42	910290	908292
JM 43B	Muzzle Stream	S42	922299	931311
JM 50A	Bluff Stream (lower)	S42	844245	883255
JM 50B	Bluff Stream (upper)	S42	878275	877279
JM 51	Gentle Annie Stream	S42	827236	827236
JM 52	Bluff River	S42	839246	839246
JM104	Woodside Creek	S36	334478	336478
JM121	Seymour Stream	S41	708125	707125
JM123	The Fell	S41	697109	698111
JM125	Wallow Creek	S48	668095	668095
JM127	Grass Seed Stream	S42	830192	825185
JM128	Limestone Stream	S42	813168	816168

For lithologic key, see Andrews, P.B. 1982: Revised guide to recording field observations in sedimentary sequences. NZGS Report 102.

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: KAIKOURA PENINSULA (SOUTH SIDE)

GEOLOGIST(S): J. MORRIS

NZMS 260 sheet: C | *serial number*: JM 1 | *horizon*: – | *remeasurement?*:

DATE OF MEASUREMENT: *day* ___ *month* ___ *year* 19___

GRID REFERENCES: (metric)

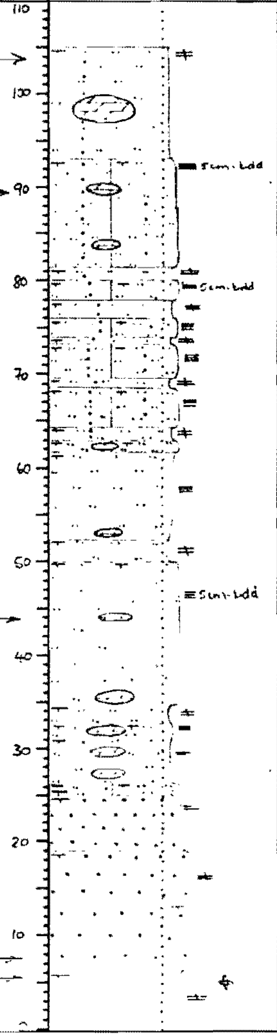
map date	BASE OF SECTION *easting*	BASE OF SECTION *northing*	TOP OF SECTION *easting*	TOP OF SECTION *northing*
19 S49 *	963	888 *	964	887 *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ______ *metres a.s.l.*

METHOD OF MEASUREMENT: TAPE AND COMPASS

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	ψ number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data ↑N
Mh	WOOLSHED FORMATION			JM 1/4 → ; JM 24/1 → ; JM 24/4 → ; JM 24/3 → ; JM 24/2 →		110 – 0				



Siltstone 80m mass, dk gy, (hd), faint lam, (bioturb), mic, non calc, slightly fs zst (units 1–15m thick) altn w sem-bdd units of lt dk gy (hd), mic, non calc, slightly fs zst & md bn-gy, hd, bioturb, mic, non calc, slightly less fs zst.
Abdt dol concretions 1–2m thick, oblate in plane of bedding, concentrated at specific horizons. Beds deformed by concs.

Siltstone 6m faintly bdd, lt gy, soft, non calc, f sst

Siltstone 12m mass, md bn gy hd, non calc f sst

MEASURED SECTION DETAIL SHEET

REGION: ____________

SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: KAIKOURA PENINSULA (SOUTH SIDE)

GEOLOGIST(S): J. MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
	c JM1	–	

DATE OF MEASUREMENT: ____ day ____ month 19__ year

GRID REFERENCES: (metric)

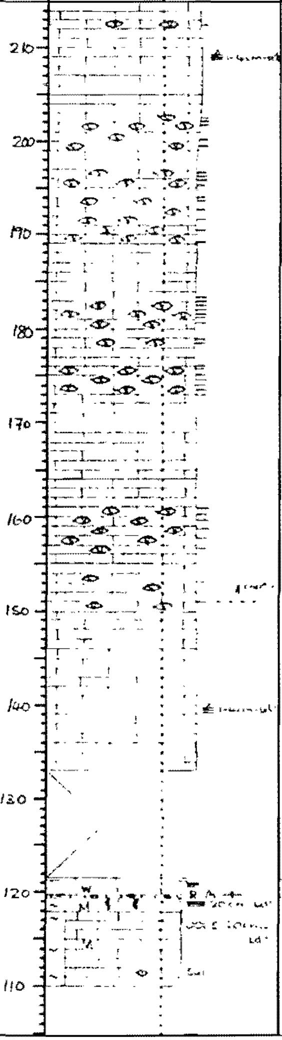
map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 S49 *	964	887 *	967	887 *

DRILLHOLES: Has thickness been corrected for dip? YES, NO

Elevation of drillhole collar ______ metres a.s.l.

METHOD OF MEASUREMENT: TAPE AND COMPASS

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
Ab / Dp						210			Limestone 55.2 m 1–4 cm bdd [illegible] Bedding [illegible] Chert [illegible] Form [illegible] contain [illegible] but [illegible]	
						200				
						190				
						180				
Dp / Dh						170				
	MIDDLE LIMESTONE					160				
						150				
						140			Limestone [illegible]	
									Limestone [illegible] dec from [illegible] % [illegible] of base to [illegible] % [illegible] of top	
Dh / Dm	LOWER MARL					130			Limestone [illegible]	
									Limestone [illegible] well bedded and [illegible] Slumped? [illegible]	
Dm / Mh		TEREDO LIMESTONE		JM1/1, JM1/2, JM1/3A, JM1/3B		120			Limestone [illegible] Mc [illegible] AbH [illegible]	
	MEAD HILL FORMATION		O31/f121	JM1/3C		110				
		WOOLSHED FORMATION								



START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ______

SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: KAIKOURA PENINSULA (SOUTH SIDE)

GEOLOGIST(S): J MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
	c JM1	–	

DATE OF MEASUREMENT: day ___ month ___ year 19___

GRID REFERENCES: (metric)

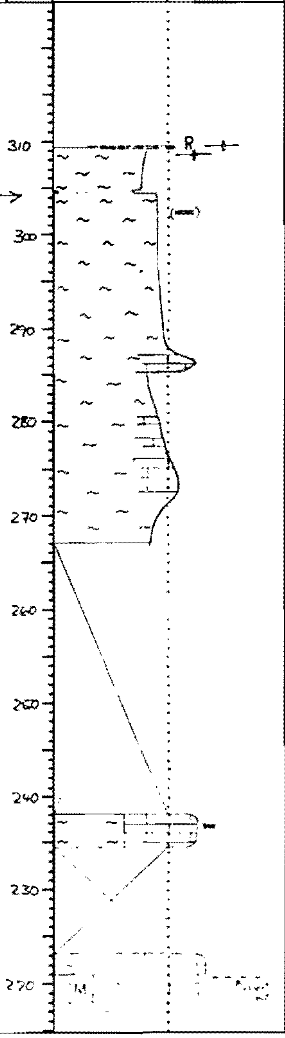
map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 S49 *	967	887 *	966	886 *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

METHOD OF MEASUREMENT: TAPE AND COMPASS

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
Lw	WEKA PASS STONE								Limestone 0.6m lt gy, hd, glc 3-5%, WhSt, Abd srt, (rare) R clasts (<5cm) intensely burrowed. 0.2m lt bn, hd, (glc) WhSt, 5mm ∅ burrows	
Ak	UPPER MARL		O31/f183 →	JM115 →		310			Limestone 4.1 m 10-50cm bdd lt md gy, (sft), Fiss. Mrl. Some intervals contain more $CaCO_3$ rich beds & so are more resistant. Bedding is only faint & is due to variations in cementation. Upper 12cm intensively burrowed, filled by dk gy, hd, glc, WhSt as above. Burrows 0.5cm long, lens	
Ak / Ab	UPPER MARL								Limestone 3.6m cm bdd lt gy, hd, pure Mrl in 50cm pockets, intbd w 50cm beds of md gy (hd) Fiss Mrl	
	MIDDLE LIMESTONE									



MEASURED SECTION DETAIL SHEET

REGION: ____ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: KAIKOURA PENINSULA (SOUTH SIDE)

GEOLOGIST(S): J. MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM 1	–	

DATE OF MEASUREMENT: day ____ month ____ year 19__

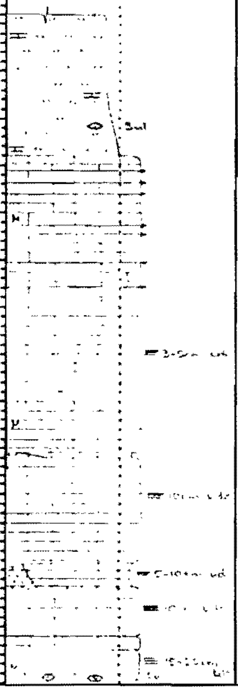
GRID REFERENCES (metric): map date 19 S49 * BASE OF SECTION: easting 966, northing 286 * TOP OF SECTION: easting 968, northing 285 *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ____ metres a.s.l.

METHOD OF MEASUREMENT: TAPE AND COMPASS

Stage	Formation	Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description	Structural data
	WAIMA SILTSTONE					380			Siltstone 200-300m 10-100cm-bdd, lt-md gy, (sft)- hd, calc, (glc) fs, Zst Basal 2m hd, & contains <5% + 5 Glc Sul nod	
			031/f133 →			370		Sul		
			031/f154 →	JM 1/9 →						
			031/f132 →			360			Limestone / Greensand 56.0m 3-20cm-bdd, lt gy, hd, s), (glc) Mc with 2-60mm thbds of gn-gy, sft, calc, f-m S, Grad Glauc beds become thinner upwards 10cm chert nodules near base Abdt sul nods near base Arenaceous ... in 1m-20cm ... Mc occur in top 5m Gc in Mc decr from 2-3% at base to ... of top	
						350		3-5cm ...		
Lw	WEKA PASS STONE					340				
						330		10cm ... bd		
			031/f184 →	JM 1/8 →		320		5-10cm ... bd		
			031/f155 →	JM 1/7 →		310				



PAGE 4 OF 4

START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ____________ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: KAIKOURA PENINSULA (NORTH SIDE)

GEOLOGIST(S): J. MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM 2	-	

DATE OF MEASUREMENT: day ___ month ___ year 19__

GRID REFERENCES: (metric)

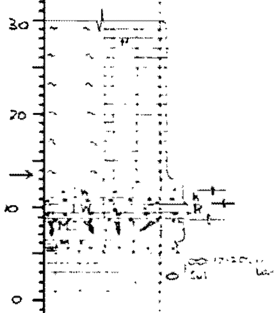
map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 S49	983	899	923	899

DRILLHOLES: Has thickness been corrected for dip? YES , NO

METHOD OF MEASUREMENT: TAPE AND COMPASS

Elevation of drillhole collar ____ metres a.s.l

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
Dh, Dm	LOWER MARL					30			Limestone 3.0m lt gy, hd, [illegible], Wthd [illegible] from [illegible] to [illegible] Grains of [illegible] out upwards	
									Limestone 0.8m lt gy, hd, [illegible], Wthd [illegible] in [illegible] burrowed	
									Limestone 0.15m lt gy, hd, [illegible], Wthd [illegible] Thin layer of [illegible] at top	
									Limestone [illegible] lt gy, hd, pure Mic [illegible] Burrows [illegible]	
						20			Limestone 1.4m lt gy, [illegible], Wthd [illegible] layer of [illegible] occurs 40cm from base [illegible] in Wthd [illegible]	
									[illegible] 0.15m [illegible] Good [illegible] burrowed	
									Limestone 2.2m lt gy, hd, pure Mic Rare 10cm [illegible] Burrows [illegible] Clastic [illegible] 4.0m [illegible] from 1m above	
			JM 2/10						Limestone 3.6m [illegible], hd-[illegible], [illegible] Mic	
Dm, Dt	TERAKO LIMESTONE					10			[illegible] 0.8m [illegible]	
Mh	MEAD HILL FORMATION					0			Limestone [illegible] lt gy, hd, [illegible] in the [illegible] round [illegible]	



PAGE 1 OF 1

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: OARO

GEOLOGIST(S): J. MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
C	JM 3	-	

DATE OF MEASUREMENT: ___ day ___ month 19__ year

GRID REFERENCES: (metric)

map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 S56	802	773	802	775

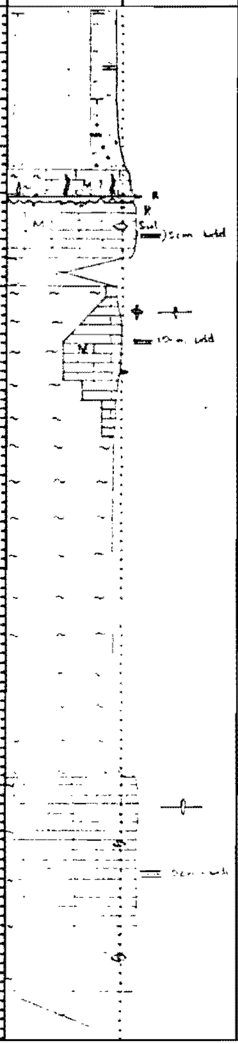
DRILLHOLES: Has thickness been corrected for dip? YES , NO

METHOD OF MEASUREMENT: TAPE AND COMPASS

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)
Lw	WAIMA SILTSTONE		032/f43 →	JM3/7 →		100
Lw	WAIMA SILTSTONE		032/f22, 032/f30, 032/f23, 032/f29, S55/f278; 032/f42 →	JM3/6 →		90
Lw	WAIMA SILTSTONE		→	JM 3/5 →		
Ar			032/f28, 032/f31 →	JM 3/4 →		80
Ak			032/f24 →			70
Ak						60
Ab	UPPER MARL		032/f40 →	JM3/3 →		50
Ab	UPPER MARL					40
Ab	UPPER MARL					30
Ab	MIDDLE LIMESTONE		032/f3? →	JM3/2 →		20
Ab	MIDDLE LIMESTONE		032/f25 →			10
						0

GRAPHIC LOG



Additional graphic

Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition

0.2m mass, m lt gy, (hd), glc Mrl. Few R granules at base fining up over a few cm
0.5m mass, mdl-br, hd, R cgl. Matrix lt gy, hd, glc Wkst. Clasts: phosphatized Mic pebbles (gran→5cm) (ang)→(rnd). Bimodal. 2-8cm lens of lt gy mic [illegible]
0.4m mass lt gy, hd, glc Wkst w R clasts [illegible] size & [illegible] toward top

Limestone ?? 5cm bdd cream, hd, (glc [illegible] fs) Mic [illegible] w [illegible] lt gy, hd, glc, Wkst & mrl partings. Glc [illegible] from [illegible] 1m from top. Rare R gran down to 1m below top

not exposed

Limestone 52.5m 10cm bdd lt gy, (hd)-md, (glc) Mic [illegible] w lt gy, slt (sft), Mrl. Bioturb. Burr infilled by [illegible] [illegible]. One 10cm lt gy, hd, glc Wkst [illegible] from top. Layer of 5-10cm pebbles (rip-ups?) of md gy, fs, glc [illegible] Wkst. Basal 25m not well exposed but assume mrl dominated

Limestone 22.7m 10cm bdd lt gy, hd (glc [illegible] fs) Mic [illegible] w [illegible] bdd, md gy, [illegible], fs Mrl [illegible]

Structural data N

PAGE 1 OF 1

START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: KAIKOURA PENINSULA (NORTH SIDE)

GEOLOGIST(S): J. MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM 4	-	

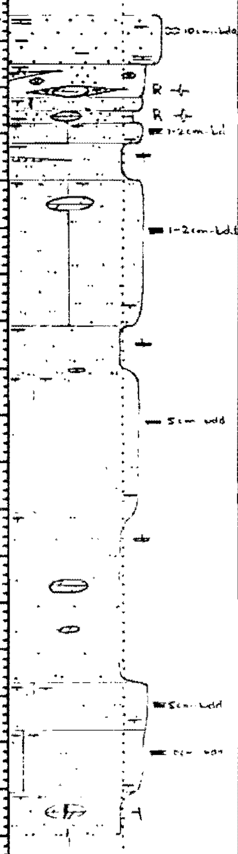
DATE OF MEASUREMENT: day ___ month ___ year 19__

GRID REFERENCES: (metric)	BASE OF SECTION		TOP OF SECTION	
map date	easting	northing	easting	northing
19 S49 *	978	898 *	978	892 *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ______ metres a.s.l.

METHOD OF MEASUREMENT: TAPE AND COMPASS

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data ↑N
Mh	CLAVERLEY SANDSTONE ~~~ WOOLSHED FORMATION			JM 4/2; JM 4/1; JM 2/2, 2/3, 2/4		0–80			see below	

Sandstone ≤1m [illegible] cm bdd [illegible] md gy hd, med calc, glc 15% f-m S, m Sst CaCO3 as streaks & patches of Mic Sil beds common near base ~1% feld grains Microcont[illegible]

Mudstone 3.6m [illegible] md gy, hd, glc 40% f-m S, q[illegible] 20% [illegible] S, s M[illegible]. Small (1mm-mm) chert nod 1-2m thick dol conc at base with rims burrowed to 5cm depth and sparse attached phos pebbles. [illegible] cm thick lenses of [illegible] glc, [illegible] M[illegible] (or chert) surrounding dol & floating in matrix. 5cm wide clastic [illegible] intrudes down

Siltstone 1.4m [illegible] cm bdd md gy, hd non calc, (bioturb) Zst

Mudstone 1.2m [illegible] md gy, [illegible] d, non calc, gc-glc, sil Mst. Gc [illegible] from [illegible]% (base) → 20% (top). Contains [illegible] Gnod 1m thick dol conc [illegible] burrowed rim [illegible] filled gy [illegible]

Siltstone 26m+ mass, dk gy, hd [illegible] (f?), faint lam, non calc, (?) Zst [illegible] w [illegible] cm bdd units of [illegible] dk gy, [illegible] non calc, (?) Zst & md [illegible] hd, bioturb, mic, non calc, [illegible] Zst. Abdt dol concs 1-2m thick. Small [illegible] conc [illegible] base [illegible] not exposed

PAGE 1 OF 2

MEASURED SECTION DETAIL SHEET

REGION: ____________

SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: KAIKOURA PENINSULA (NORTH SIDE)

GEOLOGIST(S): J. MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM 4	-	

DATE OF MEASUREMENT: day ____ month ____ year 19__

GRID REFERENCES: (metric)

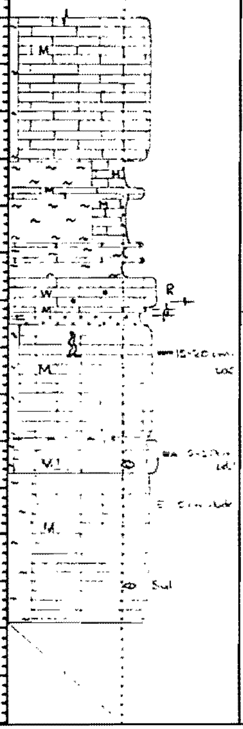
	map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19	S49 *	978	872 *	978	897 *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

METHOD OF MEASUREMENT: TAPE AND COMPASS

Elevation of drillhole collar ______ metres a.s.l

Stage	Formation	Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
	MIDDLE LIMESTONE					160, 150				
Dh										
Dm	LOWER MARL					140			Limestone 3 cm mod. [illegible] (30% f - mS) [illegible] West Spore [illegible] [illegible] pebbles < 3 cm (mode < 1 cm) [illegible] contact obscured by [illegible] Upper contact [illegible]	
				JM 4/6					Limestone 0.5 m [illegible] (nd) - [illegible], (glc), [illegible] Bioturb Burrows [illegible] [illegible] glc [illegible] West Glc decreases up [illegible]	
Dm		TEREDO LIMESTONE		JM 4/5		130		R	Sandstone 1.3 m [illegible] (nd), calc), glc [illegible] fS, f - m Sst [illegible] [illegible] 1 m below [illegible] [illegible]	
Dl				JM 4/4					Limestone [illegible] [illegible] Ld [illegible] glc [illegible] [illegible] at base [illegible]	
Mn						120		15-20 cm		
									Limestone 3 cm [illegible] Traces [illegible] [illegible] chert	
	HEAD HILL FORMATION					110			Limestone [illegible] Traces [illegible] [illegible] Bioturb	
				JM 4/3		100		Sul		



PAGE 2 OF 2

START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET, EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ____________ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: CONWAY RIVER MOUTH

GEOLOGIST(S): J. MORRIS

NZMS 260 sheet: ____ serial number: c JM 6 horizon: – remeasurement?: ____

DATE OF MEASUREMENT: day ____ month ____ year 19__

GRID REFERENCES: (metric) map date: 19 355 *

BASE OF SECTION: easting 756 northing 668 *

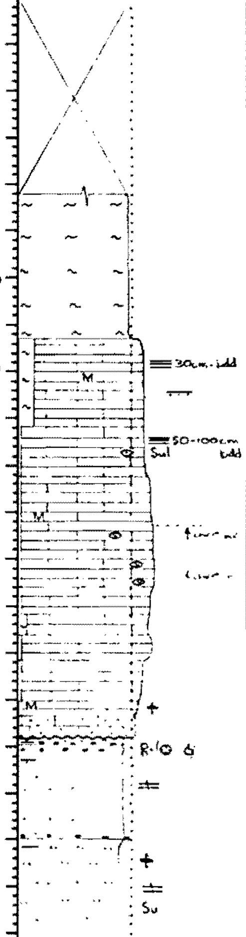
TOP OF SECTION: easting 756 northing 668 *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ____ metres a.s.l.

METHOD OF MEASUREMENT: TAPE AND COMPASS

Stage	Formation	Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data (N)
	UPPER MARL			JM 6/8 →		80			Limestone 5m+ mass, lt gy, silt-rich, Mrl. Top not exposed	
									Limestone 9.5m 20cm-bdd, lt gy, (hd) hd, Mic ltdd w 5cm m-gy, silt, Mrl. Graded base at mic at base [illegible] grad by mrl Mic then by Mrl	
						70			Limestone 5.3m 50-100cm bdd, lt gy, hd, Mic ltdd w <1cm lt gy (silt) Mrl. Traces of Glc in Mic. Sul nods	
									Limestone 6.8m 40-50cm bdd lt gy, hd-v hd, (glc, Fs) Mic itbdd w 1m intervals of 5-10cm bdd Mic of same [illegible] 5mm lt gy (silt) Mrl ltbds. Chert nods [illegible] dk gn-gy <0-5cm in thicker Mic	
	MIDDLE LIMESTONE					60			Limestone 3.0m 1-50cm bdd, lt gy, hd pure Mic itbdd w 2-30mm lt gy, (silt) Mrl. Beds decr in thickness upward. Small sul nod	
Lb									Limestone 2.5m 1-10cm-bdd, lt gy, hd (mrl) Mic itbdd w 2-10mm lt gy, (hd), Mrl	
Dp						50			Limestone 2.9m 20-40cm bdd lt gy, hd-v hd, pure Mic itbdd w cm lt gy (hd)-(silt) Mrl. Each [illegible] has 1n (mm) mrl of 5-10cm [illegible] [illegible] [illegible]	
									Limestone 6.6m [illegible] bdds lt gy, hd, Mic itbdd w 5mm lt gy hd) Mrl. [illegible] incr in thickness from 5cm at base to 15-20cm near top	
Dp									Limestone 1.0m [illegible], lt gy, (hd) v hd, (glc, Fs) Mic 2n Mrl partings. 5mm of burrows infilled w/ mid gy [illegible] Mic. Glc decr in [illegible] upwards	
Lr				JM 6/7 →		40			Limestone 0.7m [illegible] (hd) (silt) [illegible] Mic [illegible] [illegible] borings	
				JM 6/? →						
Dh						30			Limestone [illegible] mass, lt gy, [illegible] Wackestone [illegible] irregular 'pods' of mid gy [illegible] Terebratula [illegible] 20cm below top [illegible] upper contact	
Lm				JM 6/5 → JM 6/4 →					Sandstone 7.8m mass, lt gr, silt, calc, [illegible] zone of [illegible] phos clasts [illegible] Upper contact gradational over 5cm	
Dm		TEREDO LIMESTONE								
Mh	CLAVERLEY SANDSTONE			JM 6/3 →		20			Sandstone [illegible] mass, [illegible], silt, non-calc, [illegible] Glc (~2%). Basal 12cm contains [illegible] [illegible] [illegible] zone of (org)-(red) [illegible] of phosph clasts 40cm below top [illegible]	
				JM 6/2 →		10			Siltstone 5m+ [illegible], non-calc, silt, [illegible] [illegible] Sulphur stained [illegible] [illegible] upper contact	
				JM 6/1 →						
	WOOLSHED FORMATION					0				



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MEASURED SECTION DETAIL SHEET

REGION:
SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: CRIBB CREEK

GEOLOGIST(S): J. MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM7	-	

DATE OF MEASUREMENT: day ___ month ___ year 19__

GRID REFERENCES: (metric)

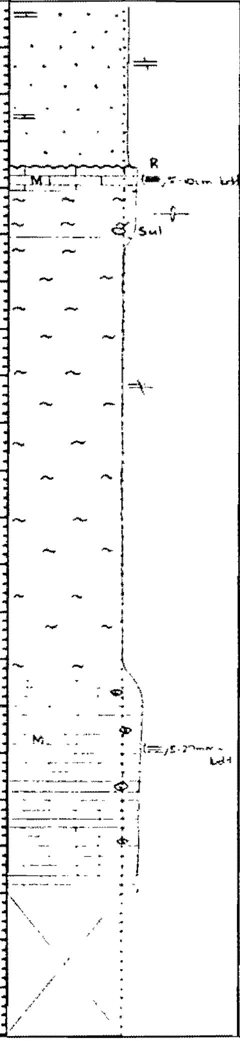
map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 S49	206	942	205	943

METHOD OF MEASUREMENT: TAPE AND COMPASS

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ___ metres a.s.l.

Stage	Formation	Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	Description	Structural data
Lw	WAIMA SILTSTONE		031/f119 →	JM7/1 →		90, 80	Sandstone 20m+ massive, m d gy [illegible], calc, [illegible] Contains 2-3% Glc [illegible] at base [illegible] upwards grading [illegible] and is absent 5m above base. Mod bioturb. Lower contact obscured	
Ak-Ar				JM7/2 →			Limestone 2.5 m 5-10cm bdd [illegible], hd, (glc [illegible] Fe), Mic	
	UPPER MARL		031/f126 →	JM7/3 →		70, 60, 50, 40, 30	Limestone 52.0m [illegible], [illegible], slt, [illegible], Mdl Occ 5cm Mic [illegible] ø sul nods Zoophycus	
Ak-Ab	MIDDLE LIMESTONE		031/f125	JM7/4 →		20, 10, 0	Limestone 22 [illegible] bdd [illegible], hd, pure Mic [illegible]	
				JM7/5 →				



PAGE 1 OF 1

START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: HAUMURI BLUFF

GEOLOGIST(S): J MORRIS

NZMS 260 sheet: C | serial number: JM15 | horizon: – | remeasurement?:

DATE OF MEASUREMENT: day ___ month ___ year 19__

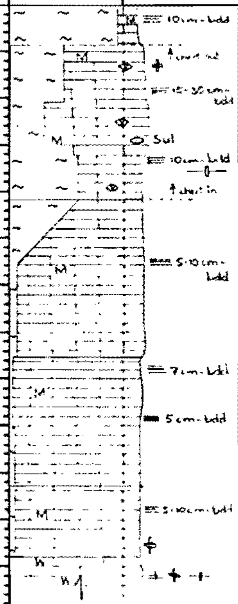
GRID REFERENCES: (metric) 19 | map date: S56 | BASE OF SECTION: easting 812 northing 733 | TOP OF SECTION: easting 813 northing 732

DRILLHOLES: Has thickness been corrected for dip? YES , NO

METHOD OF MEASUREMENT: TAPE AND COMPASS

Elevation of drillhole collar ___ metres a.s.l

Stage	Formation	Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data ↑N
	UPPER MARL					60		10cm-bdd	Limestone 16.4m 10-30cm bdd lt-gy, hd, pure Mic itbd w 5-30cm bdd lt gy [illegible]), Mrl. 10-20cm chert nods in >25cm Mic [often surr glc infilled surr] Large [illegible] bur [illegible], Small sul nod	
						50		Sul; 10cm-bdd		
Ab			022/f23 →			40		5-10cm-bdd	Limestone 16.9m 5-10cm-bdd, lt gn-gy, hd-hd, Mic itbd w 5-50mm-bdd lt gy, (hd), Mrl Mic slty impure w. [illegible] glc Mrl bds incr in thickness up.	
Dp										
Dp / Dh	MIDDLE LIMESTONE					30		7cm-bdd	Limestone 21.5m 5-10cm-bdd, lt gy, hd, (mrl) Mic itbdd w 2-5mm-bdd, lt-md gy, (hd)-(sft) Mrl Occas. 30cm Mic	
Dh / Dm						20		5cm-bdd		
Dm			S56/f512 →	[illegible] →		10		5-10cm-bdd	[illegible] (glc), f's West Glc decr → 0 upwards. Bottom [illegible] gy [illegible] Top [illegible]	
Dw		TERTIC LIMESTONE	S56/f504A, S56/f50 →	[illegible] →					Limestone 2.0m+ mass, lt yel-bn, [illegible], f's, glc, West [illegible] but [illegible] 3cm [illegible] of 'tirede' worm [illegible] 10cm [illegible] 170cm from [illegible] and [illegible] 25mm [illegible] 70cm from [illegible]) [illegible] glc (2-3%) West	
Mh	CLAVERLEY SANDSTONE					0				



PAGE 1 OF 2

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: HAUMURI BLUFF

GEOLOGIST(S): J MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM 15	-	

GRID REFERENCES: (metric)

	BASE OF SECTION		TOP OF SECTION	
map date	easting	northing	easting	northing
19 S56	813	733	212	732

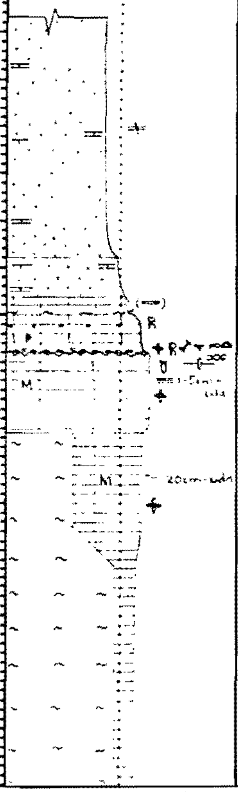
METHOD OF MEASUREMENT: TAPE AND COMPASS

DATE OF MEASUREMENT: day ____ month ____ year 19__

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
	WAIMA SILTSTONE								Siltstone 30m + mass, md-gy, [illegible], cal, [illegible]. Basal 4m [illegible] hdr. Gradational contact	
									Limestone 5.8m	
									1.6m mass, lt gy, hd, Fs (glc), Mic. Upper contact gradational	
									0.2m mass, md gy, hd, Mrl. Grades up from below	
									1.2m mass, lt gy, hd, (glc) - glc Mic [illegible]. Becomes [illegible] upwards. Glc incr 1% - 20% from base → top. Mod [illegible] 20cm [illegible] Zoophycus [illegible]. Layer of R granules (<3cm) at base [illegible]	
				140					1.4m mass, lt gy, hd, Fine, glc (3-5%), Mic. Glc decr upwards	
									0.5m 3cm bdd lt gy, hd, Fine, glc (5%) Mic [illegible] w 3-5cm-bdd md gy (hd) glc (20-30%) Mst	
				130					0.7m mass, lt gy, hd, glc Mic/Wkst. Small peb & gran phos nodules (<5mm) decrease in size & abundance upward	
			JM15/4 →	120						
	YAKA PASS STONE		032/f37 →	JM15/3 →					0.1m lt gy, (hd), R Cgl. Clst supp, [illegible], phos pbls. Abt shark teeth, vert burrows (<50mm), [illegible] [illegible]. Base of [illegible] pbls. Intense burr. Matrix lt gy, hd, glc (7%) Fs Mic	
LW			032/f36 →	JM15/2 → JM15/1, JM15/5 →		110				
				JM15/7 →					Limestone 8.5m [illegible] bdd, lt gy, hd, (glc) Mic. Upper [illegible] [illegible]. Strong burr near base. Strong burr [illegible] [illegible] burr infilled [illegible] glc Mic from above. Rare [illegible]	
						100		20cm-bdd	Limestone 41.9m 10-25 cm-bdd, lt gy, hd, pure Mic [illegible] w [illegible] gy (sft) Mrl. Horz burr [illegible] replaced by [illegible] Glc present in burr only	
	UPPER MARL		032/f25 →	JM15/6 →						
						90				
						80				
Ab			032/f24 →							
						70				



PAGE 2 OF 2

START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET, EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION:

SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: MT. ALEXANDER

GEOLOGIST(S): J. MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM 12	–	

DATE OF MEASUREMENT: 4 (day) 4 (month) 1974 (year)

GRID REFERENCES (metric): BASE OF SECTION / TOP OF SECTION

map date	easting	northing	easting	northing
19 S42 *	073	157 *	073	157 *

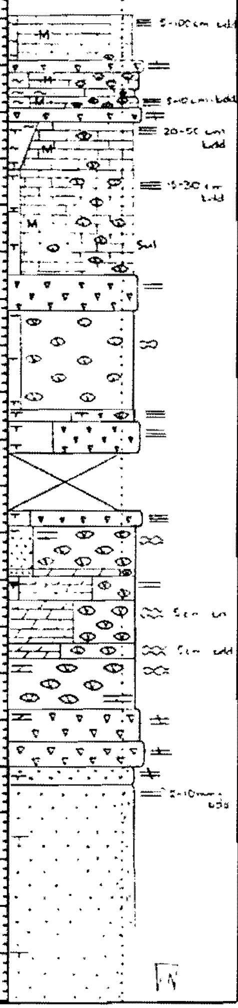
DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ____ metres a.s.l.

METHOD OF MEASUREMENT: TAPE AND COMPASS

Stage	Formation	Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	Description	Structural data
	? ?							
Dt / Mh	MEAD HILL FORMATION		P31 /f16 →	JM 12/2 →		80	Limestone 4.8m 5-100 cm bdd, lt gy, hd pure Mic, [illegible] w 1-5 cm bdd lt gy slt Mrl. <2% Chert in basal 2m present as small pink nodules. No chert above 77m	
							Chert 1.5m mass., blk, hd, Chert	
							Limestone 1.3m 5-10cm bdd Mic [illegible] w 1-3 cm Mrl 70% Chert nod	
							Limestone 0.8m 2-5 cm-bdd Mic & Mrl	
						70	Limestone 1.2m 5-10cm bdd Mic [illegible] w. 1-3 cm Mrl. 70% Chert nod	
							Chert 1.2m massive blk, hd, Chert.	
							Limestone 5.2m 20-50cm-bdd, dk gy, hd, lam Mic [illegible] w. 1-10cm bdd mrl Rst	
						60	Chert Limestone [illegible] 15-30 cm-bdd, md-dk gy, hd pure [illegible] Chert as large nodules in micrite Altn w ~10cm bdd dk gy, hd, calc Mst. 5-10mm sul nodules	
			P31/f15 →	JM 12/3 →				
						50	Chert 3.0m [illegible], lt bn hd, Chert	
			P31 /f14 →	JM 12/4 →			Chert 10.5m [illegible] dk gy, hd Chert w [illegible] dk gy, hd [illegible] Mst	
						40	Mudstone 1.3m [illegible] 5-10cm bdd sil,[hd] & non-sil[sft], dk gy Mst	
							Chert / Mudstone 3.5m 5-10cm bdd bn, hd, Chert Altn w 2-5cm bdd, dk gy, hd, non-calc Mst	
						30		
	CLAVERLEY SANDSTONE						Chert / Mudstone 1.8m 10cm bdd bn hd Chert Altn w 2cm bdd dk gy, hd, non calc Mst	
							Chert Sandstone 4.4m [illegible] [<50cm], dk bn, hd dol Chert Altn w cm bdd, dk gy hd, non-calc f Sst. Dol present as rinds	
						20	Dolomite / Chert / Sandstone 0.9m as below Chert as large isolated nodules [illegible] w 5-10cm, dk gy, hd, non-calc f Sst, and Dol.	
							Dolomite Chert [illegible] 2.7m 10cm dol beds 5cm nod Chert [illegible] 5-10mm nods, [illegible] non calc Sh	
							Dolomite Chert 4.4m as below	
				JM 12/5 →			Dolomite Chert 1.8m Chert as below) Altn w cm-bdd, [illegible] gy, slt [illegible] Dol	
						10	Chert 5.2m nodular, dk-bn hd, dol Chert Dol present as 5-10mm rind on chert nodules	
							Chert 3.6m mass, dk-bn, hd, dol, Chert Do present as scattered rhombs (10%)	
				JM 12/6 →		0	Chert 2.4m mass, dk-bn, hd, non-dol Chert.	
				JM 12/7 →			Sandstone 2m mass, [illegible] gy, hd, 3% [illegible], qtz, non [illegible] f Sst.	
Mh	WOOLSHED FORMATION						Sandstone >25m [illegible]-bdd, dk & md gy (ofn) qtz, non-calc f-m Sst, <1m [illegible] Sst [illegible] & abdt clastic [illegible] below.	

GRAPHIC LOG / Additional graphic



PAGE 1 OF 3

MEASURED SECTION DETAIL SHEET

SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

REGION:

LOCALITY: MT ALEXANDER

GEOLOGIST(S): J. MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
	c JM 18	–	

DATE OF MEASUREMENT: 4 (day) 4 (month) 19 84 (year)

GRID REFERENCES: (metric)	map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
	19 S42 *	073	157 *	072	158 *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

METHOD OF MEASUREMENT: TAPE AND COMPASS

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Samples taken and results: Petrological data	Samples taken and results: Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data ↑N
		MIDDLE LIMESTONE	P31 / f17 →	JM 5/1 >		180		5-10cm-bdd	Limestone 7.2m 5-10cm bdd ... Mc ... <mm ... Mcl ... 20-40 cm ... Mcl.	
Dh								2-5cm bdd; 2-5cm bdd; 15cm bdd	Limestone 41.9m ... -30 cm bdd ... bdd ... 5-20 cm bdd ... Stuc Mr > 2m	
Dm						170		25cm bdd; 5cm bdd; 5-15cm bdd		
						160		10-20cm-bdd; 30cm-bdd; 10cm-bdd; 25cm-bdd; 10cm-bdd		
								50cm-bdd; 25cm bdd		
						150		20-30cm bdd; 15cm bdd		
	LOWER MARL					140		10cm-bdd; 15cm-bdd		
Dm										
Dw						130		30-40cm bdd		
								5-10cm bdd	Limestone ... 5 ... Mc ... w ... 2-5mm Mcl Occ 10cm Mcl	
								5cm bdd	Limestone ... Mc ... bdd ... 2cm ...	
						120			Limestone ... w 5mm ... partings	
								10-15cm bdd		
						110			Limestone 2.8m ... 2-10cm bdd Mc	
	LOWER LIMESTONE							15cm bdd	Limestone 5.6m 15cm bdd ... bdd ... 1cm ... Mc ... Few ...	
						100			Limestone 1.9m Mcl/Mic ... below ... Chert nodules	
								15cm bdd	Limestone 4.2m 5cm-bdd ... Mc ... bdd 1cm ... Mc ... Chert rare	
						90		10cm-bdd	Limestone 13.2m 10cm-bdd ... Mc ... bdd ... 1-2cm-bdd ... Mcl Chert rare ...	
	7 ?					80				

START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ____________ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: MT ALEXANDER

GEOLOGIST(S): J. MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM 18	–	

DATE OF MEASUREMENT: 4 (day) 4 (month) 1984 (year)

GRID REFERENCES: (metric)

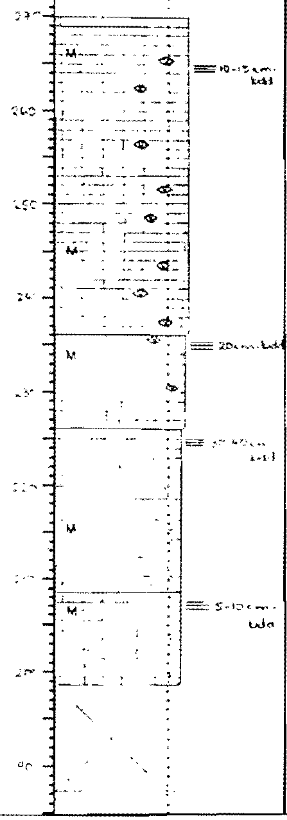
map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 S42 *	072	158 *	072	158 *

DRILLHOLES: Has thickness been corrected for dip? YES, NO

METHOD OF MEASUREMENT: TAPE AND COMPASS

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'f' number	Disturb-ance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data ↑N
								10-15cm bdd	Limestone 34 m + 10-15 cm bdd, lt gy, hd, sil, pure Mic <10% chert as small (<5cm) nodules, lt bn	
								20cm bdd	Limestone 2m 20cm bdd lt gy, hd, si, pure Mic <2% chert as <2cm irreg lt gr-gy, sil nodules	
Ab	MIDDLE LIMESTONE							30-40cm bdd	Limestone 17m 30-40cm bdd, lt gy, hd, si pure Mic	
Op								5-10cm bdd		
Dh										



START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ______

SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000)
1 cm : 50 m (1 : 5000)

LOCALITY: MORORIMU STREAM MOUTH — WAIPAPA BAY

GEOLOGIST(S): J. MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
	CJM 19	–	

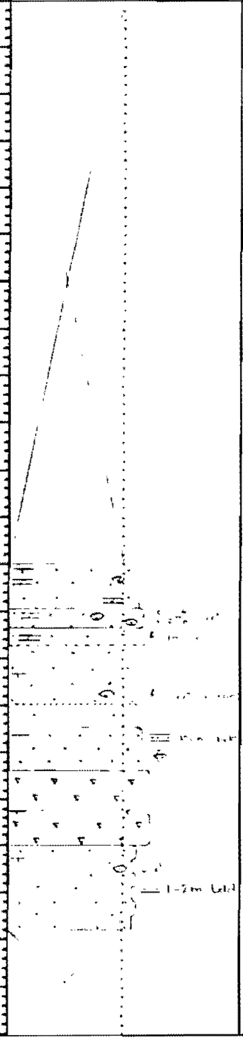
GRID REFERENCES: (metric)

map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 342 *	127	134 *	137	134 *

METHOD OF MEASUREMENT: TAPE AND COMPASS

DATE OF MEASUREMENT: day: 3 month: 6 year: 19 ..

DRILLHOLES:
Has thickness been corrected for dip? YES , NO
Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data ↑N
Mh	? ? CLAUCKLEY SANDSTONE			JM 1912 → 30; JM 1911, 1912 → 18		110, 100, 90, 80, 70, 60, 50, 40, 30, 20, 10, 0		1–2m ...	Sandstone ...; Sandstone ...; Chert 2m ...	

PAGE 1 OF 7

START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ____________ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: MORORIMU STREAM MOUTH – WAIPAPA BAY

GEOLOGIST(S): J. MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM 19	–	

DATE OF MEASUREMENT: 3 (day) 4 (month) 1984 (year)

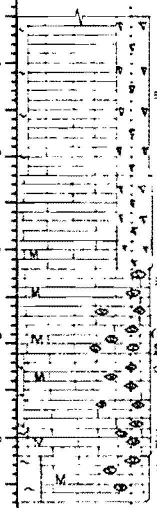
GRID REFERENCES: (metric)	map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
	19 542 *	141	124 *	141	134 *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ____ metres a.s.l

METHOD OF MEASUREMENT: TAPE AND COMPASS

Stage	Formation	Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data ↑N
						210		20-30cm bdd		
				JM 19/12		200				
Dw			P31/f45	JM 19/11					Limestone / Chert 10.0m 20-30cm-bdd, lt md gr-gy, hd [illegible] Cc [illegible] Mrl 5-30% [illegible] as 5-10cm beds	
Dt	MEAD HILL FORMATION					190		10-30cm bdd	Limestone 6.0m [illegible]-20 [illegible] bdd [illegible] gy, hd, Mic Orc [illegible] Mrl 20% chert in [illegible] cm chert rich beds [illegible] chert nod [illegible]	
				JM 19/10					Limestone 3.0m 10-[illegible] bdd, lt gy, hd, Mic bedd pll [illegible] bioturb Orc [illegible] Mrl Abdt [illegible] nod 20% chert as [illegible]	
				JM 19/9, JM 19/8		180		15-20cm bdd; Sul; 15-30cm bdd	Limestone 8.0m 5-20cm bd [illegible] gr-gy, hd, [illegible] Mic [illegible] bdd [illegible] Mrl 20% chert, dk gn gy - blk [illegible] 30cm nod	
Dt									Limestone 1.0m 10-15cm bdd, lt gn-gy, hd, (sl), Mic [illegible] bdd w [illegible] cm (hd)-hd Mrl 15% chert as [illegible] 5-10cm len nod	
Mh						170		10-15cm bdd; 5-10cm bdd	Limestone 2.0m 5-10cm bdd [illegible] gy, hd, Mic <5% Chert	
			P31/f43	JM 19/7				10-30cm bdd	Limestone 4.9m 10-30cm bdd, lt md gr-gy, hd-bd, (sl), Mic bdd w [illegible] cm bdd md gy, [illegible] platy Mrl <25% [illegible] nodules [illegible] shapes 5-100cm	
						160				
						150				
	?					140				
						130				
	?					120				
						110				



MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: MOREE MU STREAM MOUTH - WAIPAPA BAY

GEOLOGIST(S): J. MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
C	JM 19	-	

GRID REFERENCES: (metric)

map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 542 *	141	134 *	142	135 *

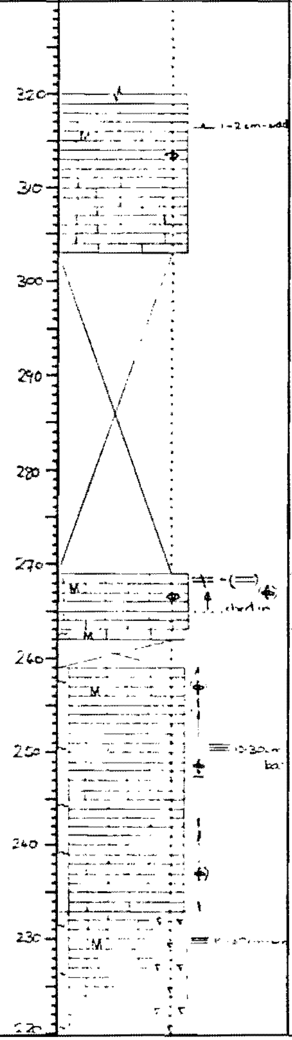
METHOD OF MEASUREMENT: TAPE AND COMPASS

DATE OF MEASUREMENT: 3 (day) 4 (month) 1984 (year)

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
	MIDDLE LIMESTONE					320–310				
	LOWER MARL					300–270				
	LOWER LIMESTONE					270–230			Limestone 6.0m ... [illegible] 5% chert ... [illegible]	
									Limestone [illegible]	
									Limestone 26.0m ... [illegible]	
									Limestone [illegible]	
	HEAD HILL FORMATION					230–220				



START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET, EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: WA PAPA BAY

GEOLOGIST(S): J. MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM19	–	

DATE OF MEASUREMENT: 4 (day) 4 (month) 1984 (year)

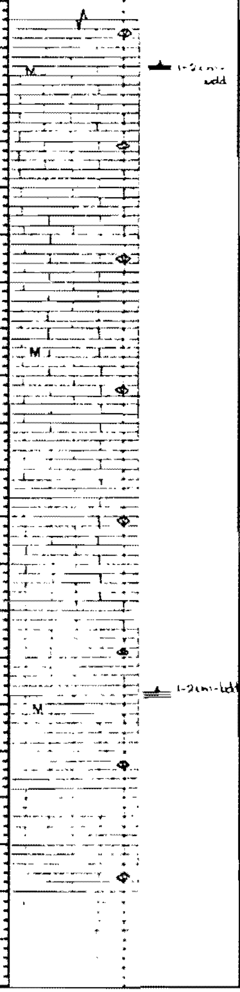
GRID REFERENCES: (metric)

map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 S42	142	135	142	136

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ______ metres a.s.l.

METHOD OF MEASUREMENT: TAPE AND COMPASS

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'f' number	Disturb-ance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data ↑N
	MIDDLE LIMESTONE					420–330		1-2cm bdd; 1-2cm bdd	Limestone 23 m 1-2 cm bdd [illegible] [illegible] 5% chert as <5cm and [illegible] sep by 50cm strat thickness	
									Limestone 97 m 1-2 cm bdd (styl), [illegible], hd, M[illegible] 5-10% chert as 5cm nodules [illegible], along bed planes sep by [illegible] strat thickness	

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: WAKAPA BAY

GEOLOGIST(S): J. MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM 19	–	

GRID REFERENCES: (metric) 19 S42 (map date) * BASE OF SECTION: 142 (easting) 136 (northing) * TOP OF SECTION: 143 (easting) 137 (northing) *

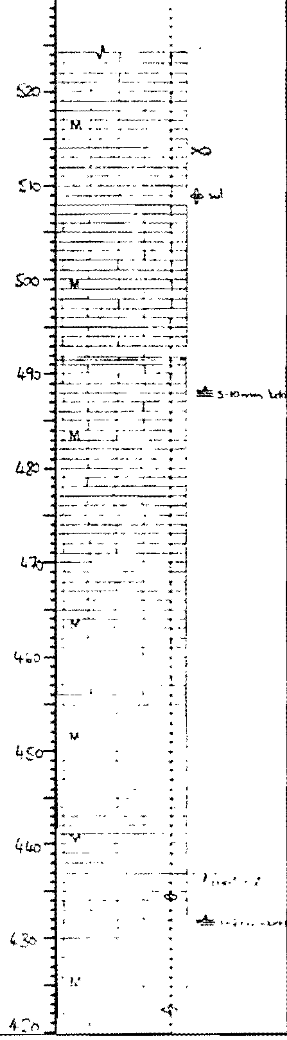
METHOD OF MEASUREMENT: TAPE AND COMPASS

DATE OF MEASUREMENT: 4 (day) 4 (month) 1984 (year)

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data (N)
	MIDDLE LIMESTONE			JM 19						



Limestone 36·4 m [illegible] bld, [illegible] gy, [illegible] unlaminated

Limestone [illegible] (glc) M[illegible] 1-2 mm [illegible] md-gy [illegible] sd and

Limestone 23 [illegible] bd [illegible] 22 [illegible] 35cm [illegible]

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START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: WAIPAPA BAY

GEOLOGIST(S): J. MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
	CJM 19	-	

DATE OF MEASUREMENT: 4 (day) 4 (month) 1984 (year)

GRID REFERENCES: (metric)

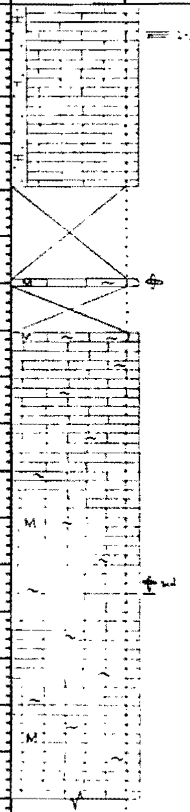
	BASE OF SECTION		TOP OF SECTION	
map date	easting	northing	easting	northing
19 S42 *	143	137 *	143	137 *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

METHOD OF MEASUREMENT: TAPE AND COMPASS

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
Lw	WEKA PASS STONE					600, 590		2-3cm bdd	Limestone / Sandstone 19.7m 2-3 cm-bdd, md [illegible], [illegible] 5mm [illegible], glc [illegible], [illegible]	[illegible]
Ab-Ar	UPPER MARL			JM 19.5		580			Limestone 1.0m mass, md [illegible], [illegible] Mic impurities [illegible] carb [illegible] Glc [illegible] bioturb	
				JM 19.5 JM 19.5		570, 560, 550, 540, 530			Limestone 22.7m faint lam (?), lt-md [illegible], [illegible], mrl Mic impurities carb? Sharks teeth Pyr & calc [illegible] here [illegible] Upper 25m highly sheared by [illegible] calc veins	



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START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: WAIPARA BAY

GEOLOGIST(S): J MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
C	JM 19	–	

DATE OF MEASUREMENT: day ___ month ___ year 19__

GRID REFERENCES: (metric)

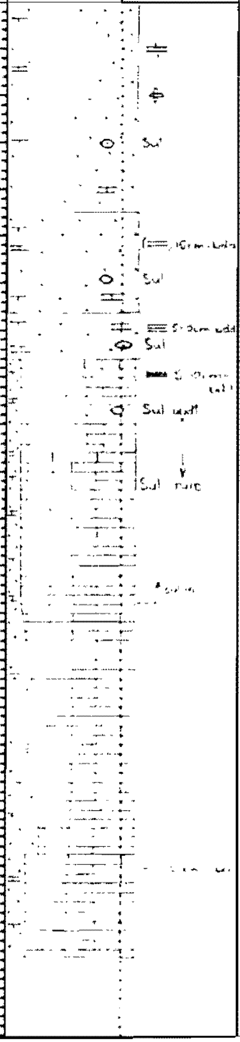
map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 S42 *	143	137 *	144	137 *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ______ metres a.s.l.

METHOD OF MEASUREMENT: TAPE AND COMPASS

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data ↑N
Lw	WAIMA SILTSTONE					700		Sul	Sandstone 33 m + mass, md-gy, hd, calc, (g'c), ± Sst. Slightly bioturb. Abdt sul nod < 5cm	
				JM 1911		690				
								10cm bdd	Sandstone 10.7 m 10 cm bdd, md-gy, hd, calc, g'c ± Sst. [illegible]	
				JM 1912		680		Sul; 5-10cm bdd; Sul	Sandstone 4.9 m 5-10cm bdd, f-md gy, hd, calc, (g'c) ± Sst, ltbdd w 2-5 cm bdd md-gy hd, calc, g'c ± Sst Sul nod abdt < 7cm	
						670		Sul abdt	Limestone/ Sandstone 11.4 m 5-10 cm bdd, md-gy, hd, f s, (g'c) Wist ltbdd w 5-10mm md-gy hd g'c, [illegible] ± Sst	
	WEKA PASS STONE			JM 1913		660		Sul rare		
						650			Limestone [illegible] 26.5 m [illegible] bdd, md gy hd, f s (g'c) Wist ltbdd [illegible] bdd md [illegible] hd [illegible] ± Sst [illegible]	
						640				
						630				
				JM 1914		620			Limestone [illegible] Wist [illegible]	
						610				



PAGE 7 OF 7

START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ____ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: PUHI PUHI RIVER

GEOLOGIST(S): J MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM 20	–	

DATE OF MEASUREMENT: day ____ month ____ year 19__

GRID REFERENCES (metric):

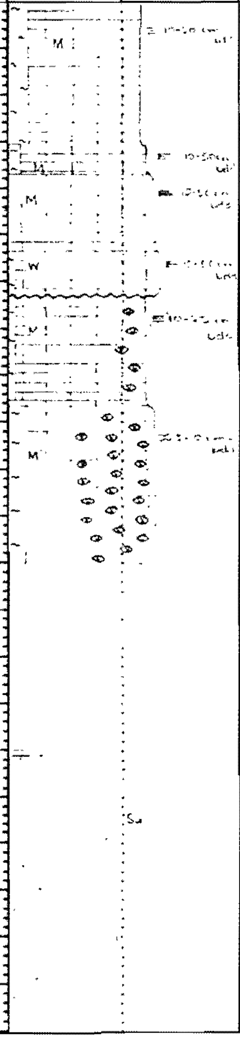
map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 S49 *	021	070 *	021	071 *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ____ metres a.s.l.

METHOD OF MEASUREMENT: TAPE AND COMPASS

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data (N)
	LOWER LIMESTONE					110			Limestone [illegible]	
			P21/f34 →	JM 20/7 →		100				
									Limestone [illegible]	
				JM 20/? →		90			Limestone [illegible]	
				JM 20/8 → JM 20/7 → JM 20/6 → JM 20/5 →					Limestone [illegible]	
Dw		TEREDO LIMESTONE				80				
Mh	MEAD HILL FORMATION		P31/f32 →	JM 20/4 → JM 20/3 → JM 20/2 →					Limestone [illegible]	
						70			Limestone [illegible]	
						60				
						50				
						40				
	WHANGAI? FORMATION			JM 20/1 →		30			Siltstone [illegible]	
						20				
						10				



PAGE 1 OF 2

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: PUHI PUHI RIVER

GEOLOGIST(S): J. MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
	C 5M 20	-	

DATE OF MEASUREMENT: day ___ month ___ year 19__

GRID REFERENCES: (metric)

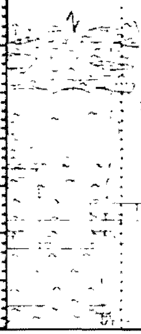
map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 S49 *	021	071 *	021	071 *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ______ metres a.s.l

METHOD OF MEASUREMENT: TAPE AND COMPASS

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
						140				
								cons. bdd 15 cm bdd	Limestone 25 cm 10-20 cm bdd in gy, hd, pure Mic bdd w 1-4 m th gy, sft Mrl Cc intense'y burr horizons	
						130				
								20 cm 20 cm bdd 20-40 cm		
				JM 20/12, 13 →				15 cm bdd		
				JM 20/11 →		120		10 cm		
?	LOWER MARL					110				



PAGE 2 OF 2

START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ______

SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: PUHI PUHI RIVER / JORDAN STREAM

GEOLOGIST(S): J. MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
C	JM 25	–	

GRID REFERENCES: (metric)	map	date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
	19	S42 *	036	109 *	035	105 *

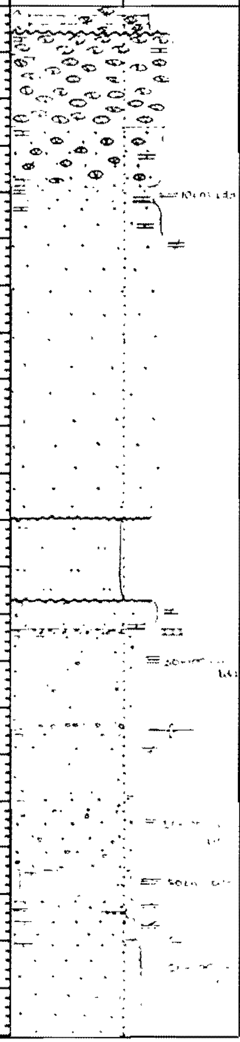
METHOD OF MEASUREMENT: TAPE AND COMPASS

DATE OF MEASUREMENT: day ___ month ___ year 19__

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data ↑N
Dw	←	LOWER LIMESTONE								
Mh	HEAD HILL FORMATION		F31/F41 →	JM 25/11 →						
	CLAVERLEY SANDSTONE		F31/F40 →	JM 25/8, /9 → JM 25/7 →					Sandstone [illegible] Sandstone 23.7 m [illegible] cals [illegible] upper [illegible]	
				JM 25/6 →					poor exposure	
Mh = Mp?		WOOLSHED FORMATION							Sandstone [illegible]	
Kn	?WHANGAI FORMATION								[illegible] Sandstone [illegible]	
				JM 25/5 →					[illegible]	
				JM 25/? →						



PAGE 1 OF 1

START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET

MEASURED SECTION DETAIL SHEET

REGION: ______

SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: CLINTON STREAM

GEOLOGIST(S): J. MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM 26	–	

GRID REFERENCES: (metric)

map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 S49 *	018	077 *	018	077 *

METHOD OF MEASUREMENT: TAPE AND COMPASS

DATE OF MEASUREMENT: day ___ month ___ year 19__

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Petrological data	Paleontological data	'f' number	Disturb-ance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description	Structural data

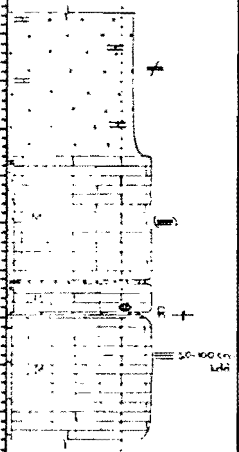
Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition.

Stage: Lw; Ab-Ar

Formation: WAIMA SILTSTONE; WEKA PASS STONE; ? UPPER MARL

'f' number:
JM26/11
JM26/10
JM26/4
JM26/9
JM26/5,6,7
JM26/2
JM 26/3

Scale (metres): 40, 30, 20, 10, 0



Sandstone 15m+ mass., md gy, hd-bd, calc, (glc). cil FS, £ Sst
gradational from lower unit

Limestone / Greensand 12 km

Greensand 20cm md-dk gy, hd, calc, Fs Gnsd

Limestone / Greensand 2.9m 10cm-bdd, md gy, hd, (glc). i?FS, Wkst
containing wispy 1cm gnsd lenses. Small chert nod at base

Sandstone 20cm lt-lt gy cN-cN, non-calc, £ Sst

Limestone 10cm, lt-md gy, hd, glc, ic? FS, Wkst contains abdt 1-5cm org. Phosph ... clasts. Burrowed

Limestone 12 m+ 50-100cm bdd ... gy, hd, pure M... ... bd ...
1-5cm ... gy ... d-bd, Mst

PAGE 1 OF 1

START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET, EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION:

SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: MEAD STREAM (MIDDLE TRIB)

GEOLOGIST(S): J C MORRIS , M LAWRENCE

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM 20 A	–	

DATE OF MEASUREMENT: 16 (day) 10 (month) 19 84 (year)

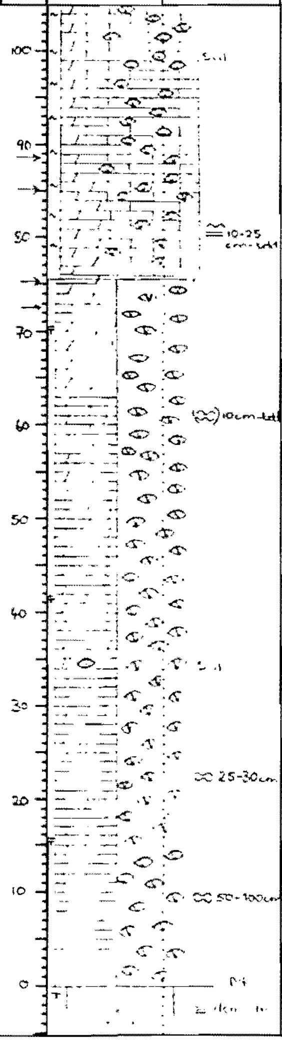
GRID REFERENCES: (metric)

	BASE OF SECTION		TOP OF SECTION	
map date	easting	northing	easting	northing
19 535	087	451	086	452

DRILLHOLES:
Has thickness been corrected for dip? YES , NO
Elevation of drillhole collar ______ metres a.s.l

METHOD OF MEASUREMENT: TAPE AND COMPASS

Stage	Formation	Petrological data	Paleontological data	number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description	Structural data
				JM 30/4					No mass dol. 30/3 = 12-15 cm lt gy, (hd), dol? calc Mrl. Trace fossil occ limited to numerous 1-3 mm thick 'streaked-out' Planolites forming pseudo-lam nae. Sharp transition from mass dol below.	
				JM 30/3						
		disseminated dol massive dol		JM 30/2					Chert / Dolomitic Mudst. 75·6 m 10-100cm-bdd dk gn, hd, med Chert Dol as 5-30cm-bdd, irreg mass hd, lt tan beds and nodules dispersed in chert 5-10 mm dk-gy, sft, non calc fissile beds. 30/1 & 30/2 show partn of 1cm lt gy, sft, dol Mrl.	
				JM 30/1						
Mh	MEAD HILL FORMATION									
Cm	← SPLIT ROCK FORMATION								Sandstone / Mudstone	



MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: MEAD STREAM (MIDDLE TRIB)

GEOLOGIST(S): J. C. MORRIS, M. LAWRENCE

NZMS 260 sheet	serial number	horizon	remeasurement?
	C ...	–	

GRID REFERENCES: (metric)

map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 S42 *	026	452 *	025	452 *

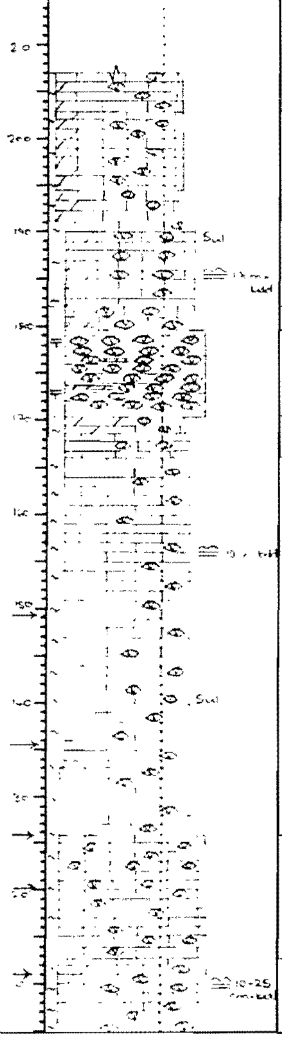
METHOD OF MEASUREMENT: TAPE AND COMPASS

DATE OF MEASUREMENT: 17 (day) 10 (month) 1984 (year)

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Petrological data	Paleontological data	'Ψ' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description (Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition)	Structural data N
						210				
									Limestone / 4 m o/b but dol decr → 10% and ceases to be main [illegible] occurs as dispersed rhombs	
						200			Limestone / Dolomite 9.5 m o/b but chert increases → 20-25%	
									Limestone / Dolomite 3.5 m o/b but sharp transn → <10% chert, 15-30% dol	
	lower chert mbr					190		Sul	Limestone, Dolomite 9 m [illegible] bdd [illegible] md [illegible] ld, [illegible] with [illegible] mrls. Dol [illegible] from rare lenses to 25-30% mass beds & lenses	
								[illegible] bdd		
						180			Chert / Limestone 2.5 m o/b but sudden decr from below to 50-60%	
									Chert 9.5 m 10cm bdd, dk-gn → blk, ld, non-calc nod bdd Chert. Sharp transition from just below Chert box [illegible] [illegible] of [illegible] (non-calc) [illegible] giving whole unit distinct [illegible] outcrop colour [illegible] shales.	
						170			Limestone / Dolomite 3 m o/b Dolomite [illegible] very [illegible] of [illegible] [illegible] non-[illegible] mass. beds [illegible] Dol only [illegible] m below top	
Mh									Limestone 2.5 m o/b Marles [illegible]	
									Limestone 40.3 m o/b Chert shows rapid transition to 30% at base [illegible] % [illegible] Slight [illegible] in [illegible] [illegible] thickness 7 m above base [illegible] [illegible] [illegible] vertical burrow [illegible] m from top upward Marles become lighter [illegible] near top	
						160		≡ [illegible] bdd		
				JM 30/9		150				
						140		Sul		
	HEAD HILL FORMATION			JM 30/8						
						130				
				JM 30/7					Limestone 12.9 m o/b no dol. Chert nod [illegible] [illegible] > [illegible] [illegible] 1 m & large [illegible] nod [illegible] [illegible] [illegible] [illegible]	
				JM 30/6		120				
			P30/F286 → no dol ↑	JM 30/5				≡ 10-25 cm bdd	Limestone 37.3 m [illegible] bdd [illegible] [illegible] hd [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] % [illegible] [illegible] [illegible] [illegible] [illegible]	



START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ______

SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: MEAD STREAM (MAIN – TRUE RIGHT – TRIB)

GEOLOGIST(S): J C MORRIS , M LAWRENCE

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM 30B	–	

DATE OF MEASUREMENT: 18 (day) 10 (month) 1984 (year)

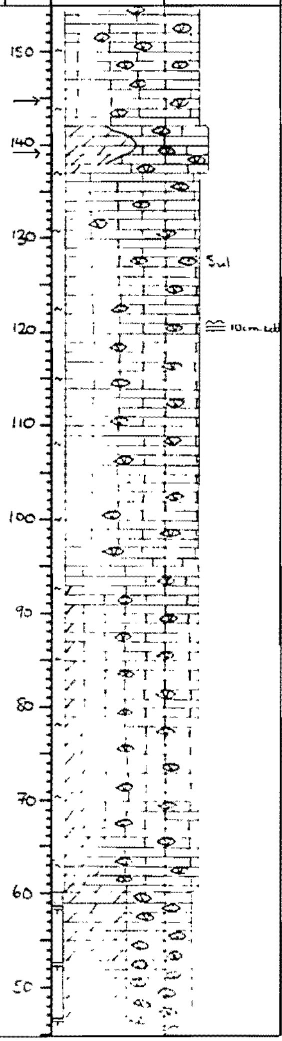
GRID REFERENCES: (metric)	map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
	19 S35 *	084	448 *	083	448 *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ______ metres a.s.l.

METHOD OF MEASUREMENT: TAPE AND COMPASS

Stage	Formation	Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data ↑N
Mh	MEAD HILL FORMATION			JM 30/12		150 – 50		Sul; 10cm bdd		
				JM 30/11					Limestone / Dolomite 4.8m — [illegible] bdd, md gy [illegible] Mic [illegible] chert. Dol appears in [illegible] as [illegible] rhombs; rapidly incr → massive beds. Some [illegible] dol [illegible] growing from beds	
									Limestone 42.0m — 10cm-bdd md gy, [illegible] pure Mic 40% chert [illegible] w. <1cm bdd, dk gy, ([illegible]). [illegible] stylolites. No dol	
		10 dol ↑							Limestone — For description see JM 30A [illegible]	
		disseminated dol / massive dol.							Limestone / Dolomite	



PAGE 1 OF 1

START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET

MEASURED SECTION DETAIL SHEET

REGION:

SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: MEEE STREAM (MEAL RANGE)

GEOLOGIST(S): J C MORRIS, M. LAWRENCE

NZMS 260 sheet | C [illegible] SOB serial number | – horizon | remeasurement?

GRID REFERENCES: (metric) 19 S35 map date

BASE OF SECTION: 083 easting, 448 northing

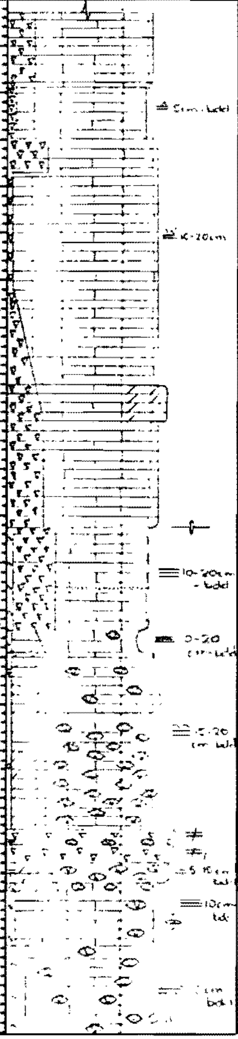
TOP OF SECTION: 082 easting, 448 northing

METHOD OF MEASUREMENT: TAPE AND COMPASS

DATE OF MEASUREMENT: day / month / 1974 year

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Samples taken and results: Petrological data	Samples taken and results: Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
Dw / Dt / Dt / Mh	MEAL HILL FORMATION; lower chert member	RIBBON CHERTS	Z. present intermittently in chert bands; Ischuchoavs; intensely bioturbated; First appearance of Zoophycos; P30/f274	Zoophycos; Zoophycos; Zoophycos; JM 30/16 ?? Thallo...; JM 30/15 Zoophycos; JM 30/14; JM 30/13		250, 240, 230, 220, 210, 200, 190, 180, 170, 160		5cm bdd; 10-20cm; 10-20cm bdd; 0-20 cm bdd; 10-20 cm bdd; 5-10cm bdd; 10cm bdd; 1cm bdd	Limestone 7.6m — 10-20cm well bedded, [illegible] no [illegible]. Base section [illegible] but dominated by [illegible] Thin Zoophycos zone 30% [illegible] chert. Limestone 0.4m — 20cm [illegible]. Limestone 5.4m — 2cm [illegible]. Limestone 41.4m — 5-20 [illegible] bedding surfaces [illegible] throughout. Base [illegible] Thallo... [illegible] Chondrites [illegible] Zooph. Distinctive [illegible] begins 10m above base. [illegible] Downward [illegible]. Limestone / Chert 10.8m — 10-20cm [illegible] Zoophycos [illegible]. Limestone / Chert 2.2m — [illegible]. Chert 19.1m — [illegible]. Chert 0.9m — [illegible]. Chert 0.5m — [illegible]. Chert 1.9m — mass [illegible] bdd chert. Chert 2.0m — [illegible]. Chert / Limestone — [illegible]. Limestone 5.8m — [illegible]. Limestone [illegible]	

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START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET, EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ____ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: MEAD STREAM

GEOLOGIST(S): J MORRIS , M. LAWRENCE

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM30B	–	

DATE OF MEASUREMENT: 18 (day) 10 (month) 1984 (year)

GRID REFERENCES: (metric)

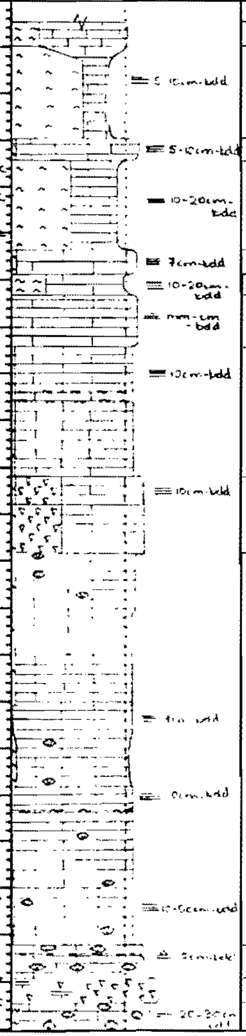
map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 335 *	C82	448 *	078	448 *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

METHOD OF MEASUREMENT: TAPE AND COMPASS

Elevation of drillhole collar ____ metres a.s.l.

Stage	Formation	Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
	LOWER MARL		Very rare Terebr... →	JM 30/27		360		5-10cm-bdd	Limestone 2.7m 5-10cm-bdd, lt gy, hd, Mic w [illegible] Mrl partings [illegible] 50cm pockets [illegible] w 5-20cm Mrls. Limestone 9.9m 5-10cm-bdd, lt gy, hd, Mic, lbd w 1-5mm marl partings in 20-50cm pockets [illegible] w 50-100cm pockets of [illegible] cm-bdd Mrl. Sparse F/C assemblage	
				JM 30/26		350		5-10cm-bdd	Limestone 2.5m 5-10cm-bdd, lt gy, hd, Mic, lbd w < 5mm Mrls. Mic & Mrls [illegible] thicker at top and bottom. Limestone 9.4m 10-20cm-bdd, lt gy, hd, Mic, lbd w 1-5mm marl partings in 50cm pockets [illegible] w 50cm marls. Z/Ch./Pl. assemblage – low [illegible]. Z. rare and is not [illegible] above.	
			P30/f105 →					10-20cm-bdd		
			P30/f288 →	JM 30/25	Rare Z					
						340		7cm-bdd; 10-20cm-bdd	Limestone 2.7m 6-8cm-bdd, lt gy, hd, Mic, lbd w 5mm Mrls. Very little [illegible]. Limestone 2.2m 10-20cm bdd, lt gy, hd, Mic in 1m pockets [illegible] w 50cm [illegible] (lt)-(hd), Mrl. Limestone 5.4m mm-cm-bdd ([illegible] 1cm), lt gy, hd Mic. No mrl or chert. Only slight [illegible] No Zoo. Abrupt change from below	
			Zoophycos out			330		mm-cm-bdd		
	LOWER LIMESTONE		P30/F290 →	JM 30/24				10cm-bdd	Limestone 14.0m 10cm-bdd, lt gy, hd, Mic, lbd w 5mm shl mrls. No chert. Very abdt Zoophycos over Planolites & Chondrites. 2 × [illegible] 10cm, lt gy, hd, (sN), Mrls	
						320				
Dm / Dw		RIBBON CHERT				310		10cm-bdd	Limestone / Chert 8.1m 10cm-bdd, lt gy, hd, Mic, lbd w 5mm shl Mrls & occ 1cm Mrls. Chert 20-30% 5-10cm thk ribbons. Abdt Zoophycos, Planolites	
			Max conc. of Zoophycos – [illegible] 2-3m Ø – one small diameter example shows at least 21 layers	JM 30/23		300			Limestone 41.8m 10cm-bdd, lt gy, hd, Mic, lbd w 1-5mm shaley Mrl partings, [illegible] rare [illegible] Mrls. Chert < 5% in basal 25m & 10% in top 6m as small nodules [illegible] absent. Planolites, Chondrites all overprinted by extremely abundant Zoophycos.	
				JM 30/22		290		[illegible] bdd		
			Z shows sharp increase in abdce							
			P30/F289 →	JM 30/21		280		[illegible] cm-bdd		
			Zoophycos present [illegible]							
				Zoophycos; JM30/20		270		10-50cm-bdd	Limestone [illegible] m [illegible] cm bdd [illegible] lt gy, hd [illegible] chert 20% [illegible]	
				JM 30/19; JM 30/18; JM 30/17		260		[illegible]; 20-30cm bdd	Chert Shale 2.7m 5-10cm bdd, [illegible] hd [illegible] Limestone [illegible] m [illegible]	
	MHF	← upper chert member	F30/F95-99 →							



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START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET

MEASURED SECTION DETAIL SHEET

REGION: ____ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: MEAD STREAM

GEOLOGIST(S): J MORRIS , M LAWRENCE

NZMS 260 sheet	serial number	horizon	remeasurement?
	C IM30 E	-	

GRID REFERENCES: (metric)	map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
	19 **	078	448	077	449

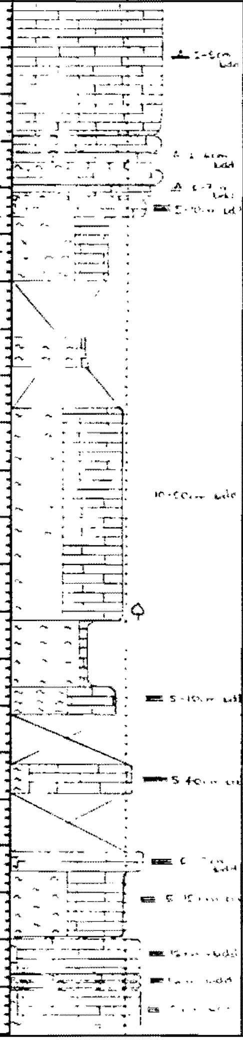
DATE OF MEASUREMENT: 20 (day) 10 (month) 1985 (year)

METHOD OF MEASUREMENT: TAPE AND COMPASS

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ____ metres a.s.l.

Stage	Formation	Petrological data	Paleontological data	# number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data ↑N
Dp						470				
Dh	MIDDLE LIMESTONE					460				
				IM 30/34					Limestone ...	
			F30/F 227 →	IM 30/33					Limestone ...	
				IM 30 /32		450			Limestone ... Top of ... Lower Marl.	
									Limestone 12 ... not exposed ...	
						440				
	LOWER MARL					430			Limestone 22.0m ... Rare Teredo ?? ...	
						420				
			?? Teredo horizon →	IM 30 31		410			Limestone 7.0m ...	
				IM 30 30		400			Limestone 5.0m ...	
									no exposure 5.5m ...	
						390			Limestone 3.0m ...	
									no exposure 6.3m ...	
			Teredo horizon →						Limestone 2.0m ...	
Dh									Limestone 7.0m ...	
Dm						380				
									Limestone 0.3m ...	
				IM 30/29		370				



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START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET, EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: HEAD STREAM

GEOLOGIST(S): J. MORRE , M LAWRENCE

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM30B	–	

DATE OF MEASUREMENT: 21 day 10 month 1985 year

GRID REFERENCES: (metric)

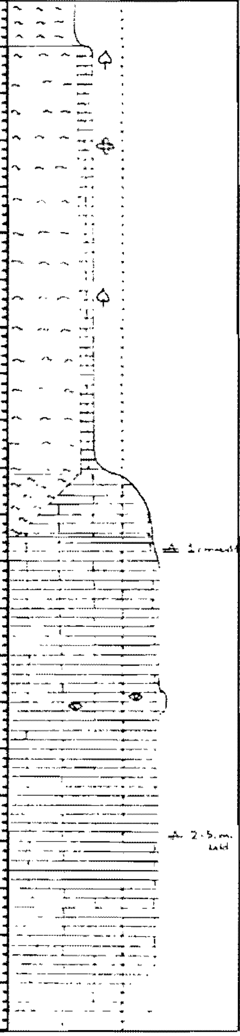
	BASE OF SECTION		TOP OF SECTION	
map date	easting	northing	easting	northing
19 S35	077	449	075	451

DRILLHOLES: Has thickness been corrected for dip? YES , NO

METHOD OF MEASUREMENT: TAPE AND COMPASS

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'F' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data ↑N
	UPPER MARL					580			Limestone 45.7m 20-30cm, H mod sn-gx, lst, Mic ctn w 50-100cm mod sn-gx mrl Contacts between mrl & mic are often gradl. All lths contain I. carb material. Abd Bpa. Highly bdture. Foss rare. Th. Hor	
				JM 30/38						
						570				
Ak / Ab						560				
				JM 30/37		550				
						540				
			P30/F182						Limestone 6.7m 1-10cm bdd, H gx, nd, Mic lbd w 5mm-40cm H gg - H sn-gx (sh?), Mrl. High degree of sheuring	
			P30/F106			530				
	LIMESTONE		P30/F285	JM 30/36				1 mud	Limestone 16cm a/b but chert present. Stylo-bdde becomes Tn (< 1cm) and lst becomes (mrly) in upper few metres	
						520				
						510			Limestone 2.2m a/b but containing 5% small chert nodules	
									Limestone 54.6m 2-5cm stylo-bdd H gg, l d, cse Mic Sc, v thn mrl < 1cm rare. Basal 5m contains 10cm mrls. No chert. Weak bioturb : Pla 10cmd, no Zoo	
						500		2.5m bdd		
Ab / Cp	MIDDLE					490				
				JM 30/35		480				



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START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: MEAD STREAM

GEOLOGIST(S): J. MORRIS , M. LAWRENCE

NZMS 260 sheet	serial number	horizon	remeasurement?
	C SM30E	–	

DATE OF MEASUREMENT: 21 (day) 10 (month) 19 85 (year)

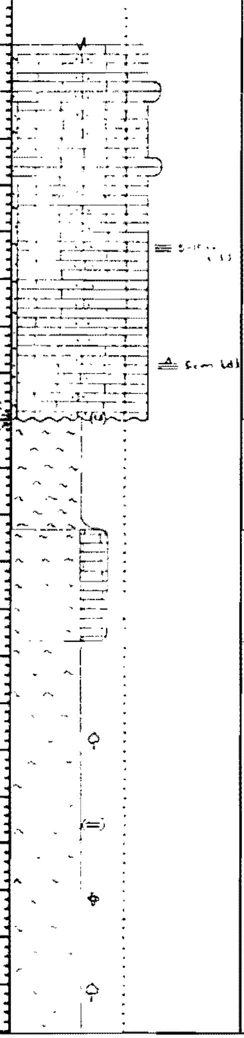
GRID REFERENCES: (metric)

map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 S35 *	075	451 *	075	442 *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

METHOD OF MEASUREMENT: TAPE AND COMPASS

Elevation of drillhole collar ______ metres a.s.l

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
	WEKA PASS STONE		Abdt Zoophycos; 3 types of Thalassinoides			690 – 680 – 670 – 660		5 cm bd	Limestone 45 m 5-15 cm bdd, md gn-gy, hd-v hd (glc f-fs). Lst thd w 5-10mm md gn-gy, (f?)-(hd), (s). ± Mdt Ang, md S grains of [illegible] – rare. Stylo-bdd in basal 6 m 2-3cm mrls every 3-4 m. Occ 1m [illegible] massive bed. Rare 30mm long [illegible]. Intensely burrowed by [illegible] Zoophycos. Z. specimens [illegible] cm thick. Sediment near [illegible] appears [illegible] by Z. Unconformably overlies U Marl. Slight ang discordance [illegible]. Base of unit shows intense [illegible] of Thalassinoides in convex hyporelief [illegible] 2 dimensions	
Lw		P30/f284, P30/f108, P30/f109 →	a) 1-2 cm Ø curved unbranched; b) 1-2 cm Ø straight branched; c) 2 mm Ø str & curv branched; Thalassinoides	2m 30142; 2m 30141					Limestone 11.6 m mass, md gn-gy, sft, Mrl [illegible], occ [illegible] Mic Abdt ± carb material. Very rich in Zoophycos + Plan/Chond	
						640 – 630			Limestone 11.7 m 20-30 cm md-gn-gy hd. Mic. thd w 50 cm lt gn-gy, sft, Mrl. Very rhythmic. First occurrence of Zoophycos (+ Plan./Chond) Zoop. can only be seen on exposed bed in wet – cannot be seen in section	
			First occurrence of Zoophycos	2m 30140 →					Limestone 46.6 m mass, md-gn-gy, sft Mrl [illegible] 10cm more cemented bands of [illegible]. Quite rich [illegible] ± carbonaceous material. Abdt small Macaroni throughout	
Ar / Ak	UPPER MARL					620 – 610 – 600 – 590				
		P30/f107 →								

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START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: MEAD STREAM

GEOLOGIST(S): J. MORRIS, M. LAWRENCE

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM 30E	–	

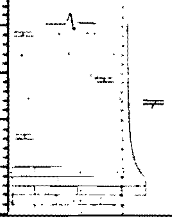
DATE OF MEASUREMENT: 21 (day) 10 (month) 19 85 (year)

GRID REFERENCES: (metric)	map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
	19 S42 *	075	442 *	075	452 *

DRILLHOLES: Has thickness been corrected for dip? YES, NO

Elevation of drillhole collar ______ metres a.s.l.

METHOD OF MEASUREMENT: TAPE AND COMPASS

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'f' number	Disturb-ance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data ↑N
						710			Waiora Siltstone 100m+ massive and [illegible] (sl4)-(hd) calc (c) Z.? Transition from Weka Pass Stone [illegible] [illegible] to [illegible]	
						700				
Lw	WEKA		Alluvial [illegible]	[illegible]						

PAGE ? OF ?

MEASURED SECTION DETAIL SHEET

REGION:

SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: LIMBURN STREAM

GEOLOGIST(S): J C MORRIS & M LAURENCE

NZMS 260 sheet	serial number	horizon	remeasurement?
C	J14 21	–	

DATE OF MEASUREMENT: 21 (day) 10 (month) 1984 (year)

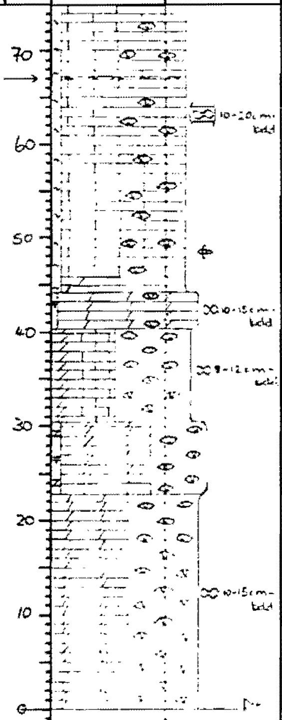
GRID REFERENCES: (metric)

map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 535 *	064	426 *	063	427 *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

METHOD OF MEASUREMENT: TAPE AND COMPASS

Elevation of drillhole collar ______ metres a.s.l

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
Mh	MEAD HILL FORMATION			FM 31/2		0–70		10-20cm-bdd; 10-15cm-bdd; 8-12cm-bdd; 10-15cm-bdd	Limestone 20.6 m 10-20cm-bdd, md gr-gz, hd, Mic [illegible] w 8-12mm [illegible] [illegible] Occ 2cm marl. 31/2 from distinct ve 5cm marl 10-15% [illegible] [illegible] in [illegible] few [illegible] out rapidly 30% chert nodules [illegible] Mod [illegible] [illegible] [illegible] Dolomite 3.8 m 10-15cm-bdd [illegible] hd [illegible] w thin [illegible] [illegible] shales, 10% chert nodules [illegible] Chert / Limestone 9.9 m 8-12cm bdd, dk gr hd [illegible] chert with [illegible] beds of [illegible] [illegible] (30%) throughout. Shale decrease in [illegible] from below Chert / Dolomite Shale 7 m a/b with thin [illegible] shales [illegible] increase in [illegible] [illegible] from below Chert / Dolomite 22.7 m 0-5 cm bdd dk gr, hd [illegible] 5cm [illegible], [illegible] beds [illegible] Dol. Very thin remnants of [illegible] preserved as [illegible] Occ 2-3cm [illegible] shale	

PAGE ___ OF 1

START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET, EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION:

SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: LIMBURN STREAM

GEOLOGIST(S): J MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
C	JM 31	-	

DATE OF MEASUREMENT: 21 (day) 10 (month) 1984 (year)

GRID REFERENCES: (metric)

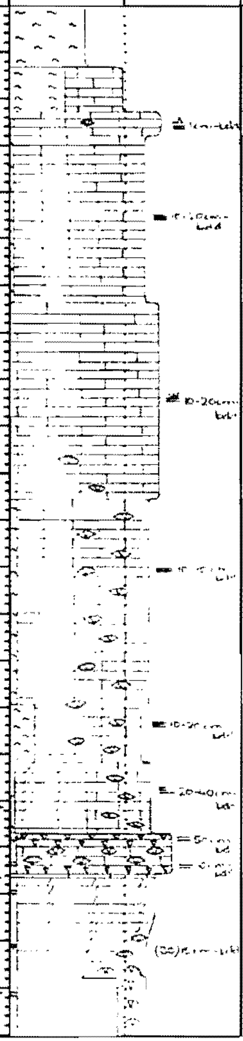
		BASE OF SECTION		TOP OF SECTION	
map	date	easting	northing	easting	northing
19	535 *	063	427 *	062	427 *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ______ metres a.s.l

METHOD OF MEASUREMENT: TAPE AND COMPASS

Stage	Formation	Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data ↑N
	LOWER MARL					120			Limestone 4.6m 10-30cm-bdd, ... in 30-60cm ... 30-50cm ...	
			?? Thalassinoides	JM 31/7					Limestone 2.6m ... bdd ... welded ... A few ... Thalassinoides burrows ...	
						170			Limestone ... marl ... every 1m ...	
Dm								10-20cm bdd		
Dw						160				
				JM 31/6					Limestone ... 10-20cm-bdd ... Chert nodules replaced ... Mod ... Zoophycos ... Lst appears "welded"	
						150				
								10-20cm bdd		
						140				
	LOWER LIMESTONE					130			Limestone ... marl decrease ...	
						120				
						110			Limestone ... Abundant Zoophycos ...	
				JM 31/...					Limestone Limonite ?.6m 20-40cm-bdd ... replaced ... First Zoophycos	
			First recognisable ... of Zoophycos	JM 31/5		100		20-40cm bdd	Chert 4.0m 10-50cm-bdd ... Chert ... upper 2m ... centre ...	
Dw	upper chert member		Zoophycos					5cm bdd		
?Mh or Dt	MEAD HILL FORMATION			JM 31/4		90			Limestone ?.3m ... Dolomite / Chert / Shale 1?.5m ...	
				JM 31/2		80		(30)cm bdd		



START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: LIMBURN STREAM

GEOLOGIST(S): ______

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM 31	–	

DATE OF MEASUREMENT: 21 (day) 10 (month) 1974 (year)

GRID REFERENCES: (metric)

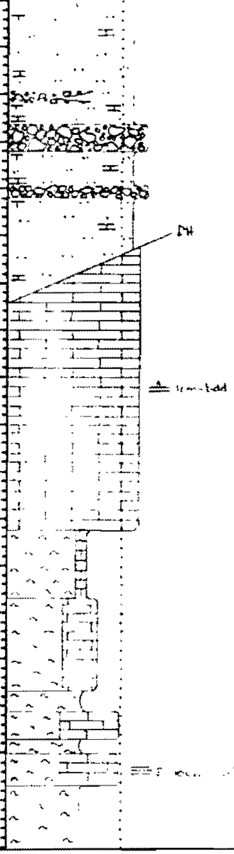
map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 [illegible]	062	427	061	427

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ______ metres a.s.l

METHOD OF MEASUREMENT: TAPE AND COMPASS

Stage	Formation	Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
	WAIMA Zst								Siltstone 30 m + mass. md [illegible] (md) [illegible] (s), [illegible] Zst Thin [illegible] Fault contact at base	
	MIDDLE LST					240			Limestone 25 m [illegible] no chert	
Dp								[illegible]		
Dn				JM 31/11		230				
				JM 31/9		220			Limestone 23 m [illegible] T/P [illegible] well defined [illegible]	
	LOWER MARL					210				
						200				
Dr				JM 31/8		190			Limestone [illegible] 40 cm pockets [illegible] Limestone [illegible]	
Dn										



START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET, EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: DEE STREAM

GEOLOGIST(S): J. C. MORRIS, M. LAWRENCE

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM 32	–	

GRID REFERENCES: (metric)

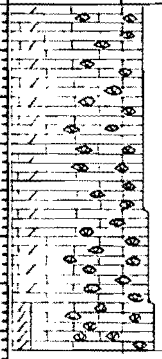
map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 S42 *	027	398 *	025	399 *

METHOD OF MEASUREMENT: TAPE AND COMPASS

DATE OF MEASUREMENT: 23 (day) 10 (month) 1985 (year)

DRILLHOLES: Has thickness been corrected for dip? YES, NO

Elevation of drillhole collar ______ metres a.s.l

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data ↑N
Mh	MEAD HILL FORMATION					40			Limestone 24 cm o/b but 20-30% chert nodules	
						30				
				JM 32/12		20 →			Limestone 10 cm o/b but ≤ 10% dol dispersed rhombs	
						10		≅ 10-25 cm bdd	Limestone 5 cm 10-15 cm-bdd, lt gy, hd, sil, Mic w 2-8 mm mdls, 30-40% chert nodules, 10% dol as mosc lenses.	
						0				

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START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: DEE STREAM

GEOLOGIST(S): J MORRIS, M. LAWRENCE

NZMS 260 sheet: ______ | serial number: c JM 32 | horizon: - | remeasurement?: ______

DATE OF MEASUREMENT: 23 (day) 10 (month) 19 85 (year)

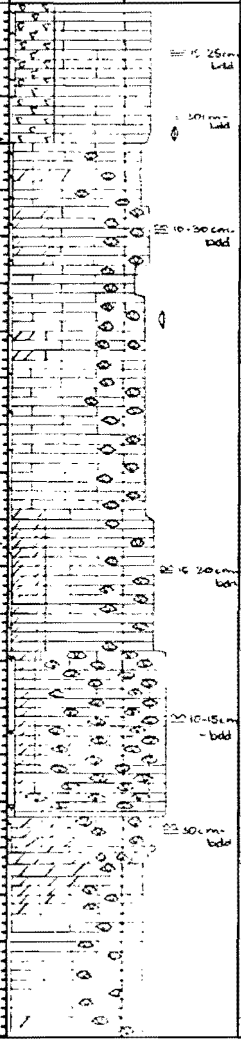
GRID REFERENCES (metric): 19 S42 (map date) * BASE OF SECTION: 025 (easting) 399 (northing) * TOP OF SECTION: 024 (easting) 400 (northing) *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

METHOD OF MEASUREMENT: TAPE AND COMPASS

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'f' number	Disturb-ance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
?	MEAD HILL FORMATION					150			Limestone 8.?m o/b but 1-3cm marls at 1m intervals	
						140			Limestone 9.0m 30cm bdd, lt gy-gy, hd, pure Mic w 1mm marl partings. Chert 30% as cont ribbons. T.F. = *Planulites / Chondrites*, No *Zoophycos*. NB large benthic forams & spines/spicules at base	
			JM 32/10						Limestone 7.8m o/b no dol. Rapid change from nod → ribbon chert	
						130			Limestone 1.4m o/b with ≤20% dispersed dol rhombs	
?									Limestone 2.5m 20cm-bdd, lt gy, hd, Mic, Itd w 5-10mm mrls, 10-15% chert nodules	
									Limestone / Dolomite 6.4m 10-30cm-bdd, lt gy, hd, sil, non-calc, Mic w thin shale lbds. 25-30% chert nodules 30% mass dol beds	
						120			Limestone 3.2m o/b but 10-15% chert	
?						110			Limestone 23.1m 10-30cm-bdd, lt gy, hd, Mic w 5-10mm marl partings, 20-25% chert nodules. No dol apart from 2 ½ m zones. Large forams dispersed by etching on bedding surfaces. 20% dispersed dol rhombs; 5-10cm mass lenses totalling 20%	
						100				
			JM 32/11			90			Limestone / Dolomite 15.0m 15-30cm-bdd, lt gy, hd, sil Mic Itd w 1cm sft, fiss, (calc), mrls. Bddg mod nodular 20-25% dol as mass beds. 20-30% chert nodules	
Mh	lower chert member					80			Chert 16.6m 10-15cm-bdd, dk gy, hd, sil, non-calc, Mic Itd w 5-10mm sil shales 60-70% chert nod. Small amount dol as mass beds. Sharp base. Poorly exposed	
						70				
						60			Limestone 3.8m 30cm-bdd, md gy, hd, Mic Itd with 5mm mrls 30-40% chert nodules. Dol as dis rhombs 5-10%	
									Dolomite 1.0m 30cm-bdd, mass, rex. Dol. 10-15% chert nods	
									Limestone 5.2m o/b but 30-40% dispersed dol rhombs at top decreasing to nil at base	
						50			Limestone 11.2m o/b but no dolomite	
						40				



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START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: DEE STREAM

GEOLOGIST(S): J C MORRIS M. LAWRENCE

NZMS 260 sheet	serial number	horizon	remeasurement?
C	JM 32	–	

DATE OF MEASUREMENT: 23 (day) 10 (month) 1984 (year)

GRID REFERENCES: (metric)

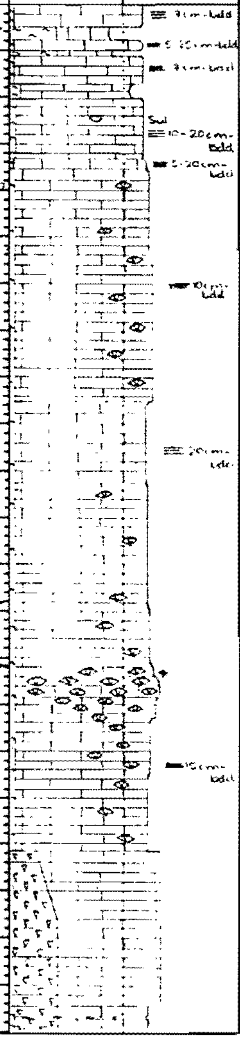
map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 S35 *	024	400 *	023	400 *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ______ metres a.s.l

METHOD OF MEASUREMENT: TAPE AND COMPASS

Stage	Formation	Petrological data	Paleontological data	'f' number	Scale (metres)	Description
Dm / Dw	LOWER LIMESTONE			JM 3215	260	
			Zaphrentoides appears here		250	Limestone 6.4m 10-20cm-bdd, lt gy, hd, pure Mic w 2-3mm mrl prtgs 5-10mm marls every ~2m No chert
			Very common in Zaphrentoides		240	Limestone 9.8m a/b but sudden decrease → 5% chert
					230	Limestone 16.2m a/b but sudden increase → 10% chert
					220	Limestone 8.7m a/b but no chert. No Zaphrentoides
			Zaphrentoides	JM 3216	210	Limestone 13.3m a/b but only 1-2% chert, 2 distinct levels of Zaphrentoides
			Zaphrentoides		200	Limestone 6.4m a/b but only 2-3% chert
				JM 3217		Limestone 1.4m 15-25cm-bdd, lt gn-gy, hd, pure Mic itbd w 2-6mm lt gn-gy sft Mrl 7% chert nodules, Mic well bdd Abdt Zaphrentoides + Chonetes / Pleurodictyum Basal 25cm intensely bioturbated
Dw	upper chert member	upper chert member	Zaphrentoides	JM 3218	190	Limestone 2.2m 10cm-bdd, lt gn-gy, hd, Mic - sil itbd w 5mm marls 60% chert at base 45% chert at top Zaph. only at top Rusty weathering
	HEAD HILL FORMATION					Limestone 2.3m a/b but 30% chert
					180	Limestone 8.2m a/b but 10% chert
						Limestone 7.8m 15cm-bdd lt gn-gy, hd, Mic itbd w 5-10mm shaly beds No Zaphrentoides Abdt Pleurodictyum 5% chert
					170	Limestone 16.6m 15cm-bdd, lt gn-gy, hd Mic No marl Mic appear "welded" along b.p.s. 20-30% chert as continuous ribbons
			Tentaculites + Zaphrentoides		160	
?				JM 3219	155	



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MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: DEE STREAM

GEOLOGIST(S): J C MORRIS M LAWRENCE

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM 32	–	

DATE OF MEASUREMENT: 23 (day) 10 (month) 1985 (year)

GRID REFERENCES: (metric)

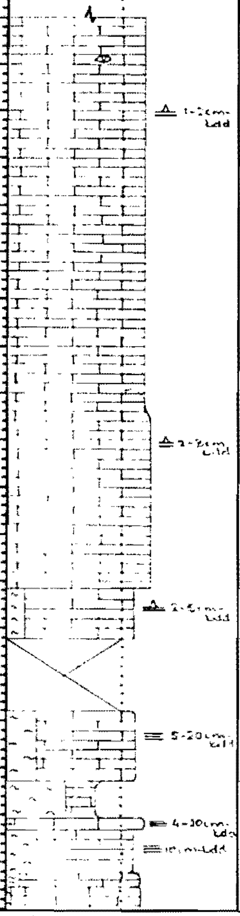
map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 S35 *	023	400 *	022	401 *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

METHOD OF MEASUREMENT: TAPE AND COMPASS

Elevation of drillhole collar ______ metres a.s.l

Stage	Formation	Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data ↑N
Ld / Lf	MIDDLE LIMESTONE			JM 32/1		350, 340, 330		1-2cm-bdd	Limestone 60·8m 1-3cm-bdd (Stylo-bdd), lt gy, sl[?] [illegible] Mic. No mrl. Very rare chert – only at top. Very rare biotite – Plan/Crand. A few 5-8cm beds near base	
Dp / Dh	MIDDLE LIMESTONE					320, 310, 300		2-3cm-bdd		
				JM 32/2		290		2-5cm-bdd	Limestone 5·3m 2-5cm-bdd, stylo-bdd lt gy Mic w occ 5-20cm bands of marl	
									not exposed 8·0m	
Dh / Dm	LOWER MARL			JM 32/3		280, 270		5-20cm-bdd; 4-30cm-bdd; 10cm-bdd	Limestone 7·3m 5-20cm-bdd lt gy, hd Mic itbd w thin mrl partings in 50-200cm packets alt w 10-40cm, lt gy (hd) Marl. Rare Zoophycos with Plan/Crand.	
	LOWER LIMESTONE			JM 32/4		260			Limestone 12·7m 10cm-bdd lt gy, hd Mic itbd & alt w 10-50cm lt gy, sft Mrl	



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START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ______

SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: BRANCH STREAM (NORTH TRIB'

GEOLOGIST(S): J C MOORE , M LAWRENCE

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM40A	-	

DATE OF MEASUREMENT: 6 (day) 11 (month) 1984 (year)

GRID REFERENCES: (metric)

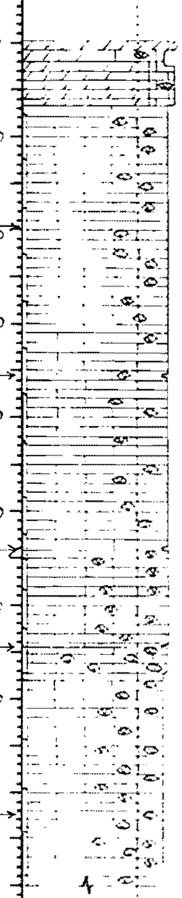
map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 S42 *	012	380 *	011	381 *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ______ metres a.s.l

METHOD OF MEASUREMENT: TAPE AND COMPASS

Stage	Formation	Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
						90			Dolomite 0.9m mass, lt gy, hd Dol Dolomite 1.8m o/b but only 50-70% dol replacing mic. Dolomite 4.3m 7-12cm bdd, md gy, hd Mic itbd w 1-3mm shaly marls Mod [illegible] [illegible] [illegible] [illegible] 10-15% chert lk gn >90% dol replacement - mass bed	
						80			Limestone 25.9m o/b	
				JM 40/5		70				
Mh						60				
	MEAD HILL FORMATION			JM 40/4					Limestone 8m o/b but 20% chert Occ 15-20cm well bdd mic w core thick marl Top marked by 15cm marl	
						50				
						40				
				JM 40/3					Limestone 10.3m o/b but chert [illegible] [illegible] Base marked by 2 x 1cm marls sep by 4cm mic Top marked by 2 x 5-10cm marls sep by 0.4 cm mic Both horizons very distinct due to pref erosion	
						30				
				JM 40/2					Limestone 2.4m o/b but 30-40% chert	
						20			Limestone 21.8m 5cm bdd, lt-md gy, [illegible], hd Mic itbd w 4m (mm) shaly marls Nodular bdg. 2% chert as md gn gy nodules	
				JM 40/1		10				
						0				



PAGE 1 OF 6

START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: BRANCH STREAM (NORTH TRIB)

GEOLOGIST(S): J. MORRIS, M. LAWRENCE

NZMS 260 sheet: ______ serial number: C JM 40A horizon: – remeasurement?: ______

GRID REFERENCES (metric): BASE OF SECTION: map date 19 S42 *, easting 011, northing 381 *; TOP OF SECTION: easting ______ northing ______ *

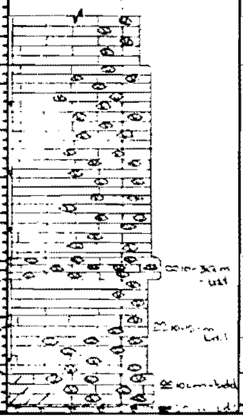
METHOD OF MEASUREMENT: TAPE AND COMPASS

DATE OF MEASUREMENT: day 6, month 11, year 1985

DRILLHOLES: Has thickness been corrected for dip? YES, NO

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data ↑N
									NO EXPOSURE	
	MEAD HILL FORMATION					130			Limestone 6.2 m a.b. but marls are calc. Slow transition to 25-30% chert from below	
				JM 40/11					Limestone 20.2 m 10-20 cm bdd. lt-md gy. hd. sil. calc. Mic. itbd w 2-5 cm sil. shales. 20-50% chert nodules. Good bedding. Chert nodules at base are almost cont. and laminated – becoming nodular up	
						120				
				JM 40/10		110			Chert 2.2 m 10-30 cm bdd. blk. hd. nod. chert with rinds of sil. mic. itbd w 1 cm non-calc. shales	
	lower chert member			JM 40/9				20-30 cm ...	Limestone 4.5 m 10-15 cm bdd. ... sil. lt. Mic. itbd w 2-8 mm sil. non-calc. shales. 20% dk gn chert nodules	
Mh				JM 40/8						
						100			Limestone 3.5 m a.b. but no del. 1-2 cm (w occ. 5-10 mm) marls	
				JM 40/7				... cm	Limestone 3 m 7-12 cm bdd. lt-md gy. hd. sil. Mic. itbd w 1 mm marls. 20% chert nodules. Mass del. 20% at base. Decrease up to 10% of ... and ... out	
				JM 40/6				... cm bdd	Limestone 0.2 m 3-5 cm bdd. lt gy. mass del. 20-30% chert 5-10 mm shale	
						90			Chert 0.6 m 20 cm bdd. blk. hd. int. 1 cm chert itbd w 5 mm beds of mass del. Sharp lower contact	



PAGE 2 OF 2

START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET, EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: BRANCH STREAM (MIDDLE)

GEOLOGIST(S): J. C. MCGRE[illegible] M. F. LAWRENCE

NZMS 260 sheet	serial number	horizon	remeasurement?	DATE OF MEASUREMENT:
	C JM 40 B	–		day 7 / month 11 / year 1984

GRID REFERENCES: (metric)

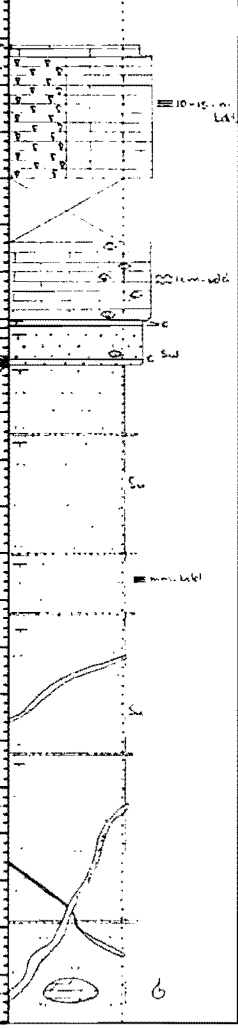
map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 S42 *	008	375 *	007	376 *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

METHOD OF MEASUREMENT: TAPE AND COMPASS

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
	MEAD HILL FORMATION			JM 40/ A JM 40/ 8					Limestone 2-3 cm mass. [illegible] Limestone [illegible] a/b [illegible] Very sharp [illegible] Limestone [illegible]	
						200		10-15 cm bd		
						240			150 m [illegible] not measured due to [illegible] waterfall	
						80		[illegible] bdd	Limestone [illegible]	
Mh		CLAVERLEY SANDSTONE	S42/f681 → S42/f541 →	JM 40/16 JM 40/17 JM 40/15 JM 40/14 JM 40/13				Sw	Sandstone [illegible] mass. [illegible] (hd), non-calc. [illegible] [illegible] lens 70 cm [illegible] Top [illegible] Top may be unconformable [illegible] [illegible] Very [illegible] material [illegible]	
	WOOLSHED FORMATION					60 50 40 30 20 10		Sw [illegible] bdd Sw 6		
				JM 40 [illegible]						



PAGE 1 OF 2

START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: BRANCH STREAM / MCLEE TRB

GEOLOGIST(S): J C MERRIS M LAWRENCE

NZMS 260 sheet	serial number	horizon	remeasurement?
C	JM 40 B	–	

GRID REFERENCES: (metric)

map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 542	006	377	006	378

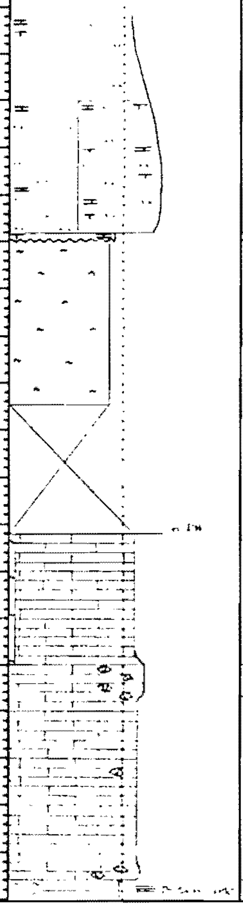
METHOD OF MEASUREMENT: TAPE AND COMPASS

DATE OF MEASUREMENT: 7 (day) 11 (month) 1984 (year)

DRILLHOLES: Has thickness been corrected for dip? YES, NO

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
	WEKA PASS STONE								Siltstone 20 m [illegible]	
						180			Siltstone 15 m 20-40 cm bdd, md gn-gy, hd, calc [illegible]	
				JM 40/25					Mudstone 10 m lam, red-bn (hd), calc, Mst w small scale x-bdd [illegible]	
			030/f93	JM 40/24, JM 40/23, JM 40/22		170				
Lw / Ak	UPPER MARL		030/f92	JM 40/21					Limestone 40 m + mass, lt gy, sft, Mrl poorly exposed	
						160				
Ab						150			poorly exposed section containing approx 100 m of M Lst contacts with U & L Marl not seen	
	MIDDLE LIMESTONE					40			Limestone [illegible]	
At / Dp						30				
									Limestone [illegible]	
						20			Limestone [illegible]	
Dp / Dh				JM 40/20		10				
	LOWER MARL					0			Limestone [illegible]	



PAGE 2 OF 2

START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: WHISKY STREAM

GEOLOGIST(S): JOHN C MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
O30	C JM 41	-	

DATE OF MEASUREMENT: 8 (day) 11 (month) 19 84 (year)

GRID REFERENCES: 542

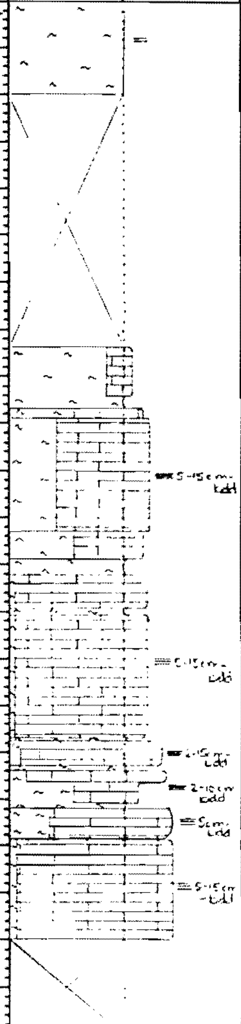
	BASE OF SECTION		TOP OF SECTION	
	easting	northing	easting	northing
542	997	362	996	362

DRILLHOLES: Has thickness been corrected for dip? YES , NO

METHOD OF MEASUREMENT: TAPE AND COMPASS

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
			O30/f98 →	JM 41/4		100			Limestone 12m mass., lt gn-gy, sft-(sft) Mrl with occ 1m pockets of 5-10cm bdd Mics.	
						90				
						80			no exposure 27m assume marl	
						70				
						60			Limestone 6.5m 5-10cm-bdd lt gy, hd, Mic in 20-40cm pockets within Mrl	
				JM 41/3 →					Limestone 15m 5-15cm-bdd, lt gy, hd Mic ibdd w 5-10mm Mrls in 50-60cm pockets sep by 30-50cm Mrls	
	LOWER MARL					50		5-15cm-bdd		
				JM 41/2 →		40			Limestone 1.5m mass lt gy, sft Mrl	
									Limestone 17.5m 5-15cm bdd, lt gy, hd Mic ibdd w 2-5mm Mrls in 1m thick pockets sep by 15-25cm Mrls. Arenaceous 70cm Mrl 13m above base	
						30		5-15cm-bdd		
						20		5-15cm-bdd	Limestone 3.5m 2-10cm-bdd lt gy, hd, Mic ibdd w 5 mm Mrls. Mics 5cm top & base, 2cm centre. Thick mrls top & base	
								2-10cm-bdd	Limestone 3.5m 1-2cm-bdd lt gy, hd Mic ibdd w 1-2cm lt gy, sft Mrl. 60cm nil at base. Mics are to 10cm near top	
Dm								5cm-bdd	Limestone 2.7m 5cm-bdd lt gy, hd, Mic ibdd 1-3mm (sft) Mrls. 30cm near m. of base. Burrows common at base	
Dw			O30/f97 →	JM 41/1 →		10			Limestone 10.4m 5 5cm bdd, lt gn-gy, hd, (s), pure Mic ibdd w 1-10mm lt gn-gy, (hd), shaley Mrls. Low disturb form Planolites 1-2cm, ? ... nodules on bp weathering ... may be Thalassinoides	
	LOWER LIMESTONE		Thalassinoides ? →			5-15cm-bdd				
						0			no exposure ... base ...	



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MEASURED SECTION DETAIL SHEET

REGION:

SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: WHISKY STREAM

GEOLOGIST(S): JOHN C MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
D30	C JM 41	-	

DATE OF MEASUREMENT: 8 (day) 11 (month) 1984 (year)

GRID REFERENCES: (metric)

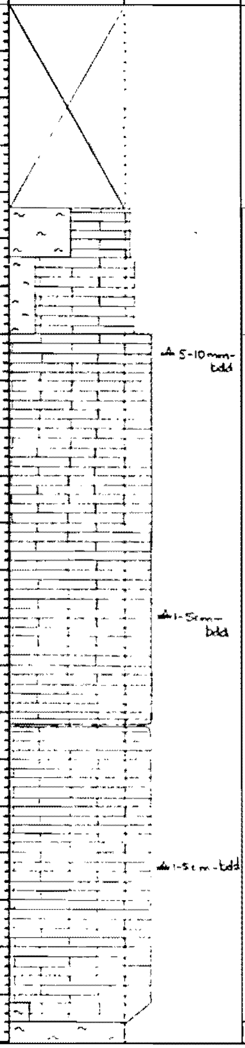
map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 842*	996	362*	995	363*

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ______ metres a.s.l

METHOD OF MEASUREMENT: TAPE AND COMPASS

Stage	Formation	Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	Graphic log	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
						190			poor exposure	
	UPPER MARL		030/f100 →	JM 41/6		180			Limestone 13m+ 5-10cm bdd mic a/b in 50cm packets ibdd w 10cm mrls at base and 50cm mrls at top	
	MIDDLE LIMESTONE					170		▲ 5-10mm-bdd	Limestone 73m 1-5cm stylo-bdd, lt gy, hd, Mic, B.P's stylolitized - No mrls 10cm anomalous marl 30m above base. Bed thickness decr. to 5-10mm in upper 50cm	
						160				
Ab / Dp						150		▲ 1-5cm-bdd		
						140				
			030/f99 →	JM 41/5						
						130				
						120		▲ 1-5cm-bdd		
Dp / Dh						110				
						100				



PAGE 2 OF 2

START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET, EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: CART STREAM (SOUTH FORK)

GEOLOGIST(S): JOHN C MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
O30	C JM 42	–	

DATE OF MEASUREMENT: 10 (day) 11 (month) 1984 (year)

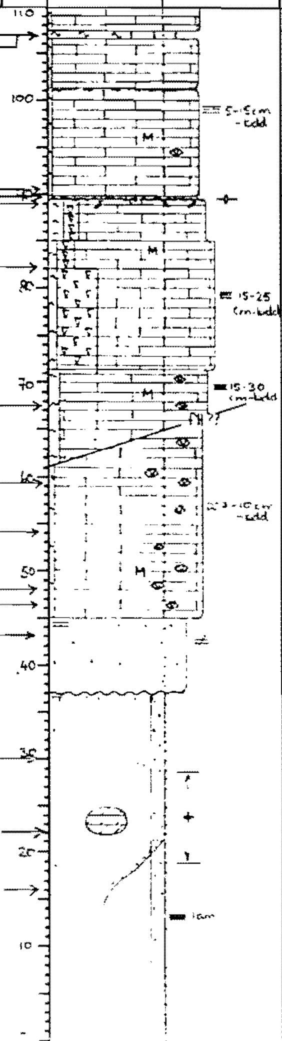
GRID REFERENCES: (metric)

map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 542 *	973	340 *	970	339 *

DRILLHOLES:
Has thickness been corrected for dip? YES , NO
Elevation of drillhole collar ______ metres a.s.l

METHOD OF MEASUREMENT: TAPE AND COMPASS

Stage	Formation	Petrological data	Paleontological data	'f' number
	LOWER LIMESTONE	030/F101 →	*Teredo* tubes →	JM 42/17, JM 10/6
			Rare *Zoophycos*	
Dw		← TEREDO LIMESTONE		JM 42/15
	MEAD HILL FORMATION	030/F140	Echinoid spines, spicules	JM 10/5, JM 42/14
		030/F141 →	Abdt *Zoophycos* (430?)	JM 42/13A
Dw				JM 42/13
Mh				JM 42/12
			Echinoid spines	JM 42/11
		030/F50, 030/F136		JM 10/1, JM 42/1
	FLAXBOURNE SANDSTONE	030/F49		JM 10/3
				JM 42/2, JM 10/2
	WOOLSHED FORMATION	030/F120 →		JM 42/3
				JM 10/4



Description

Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition

Limestone 80cm 25cm-bdd, lt gy, sft. Mrl ibdd w 25cm Mic

Limestone 5.2m 5-15cm-bdd, lt gy, hd, pure Mic ibdd w 1-5mm Mrls Rare 10cm 0.5cm mrls Occ *Zoophycos*. Rare chert

Limestone 25cm 10-15cm-bdd, lt-md gy, hd, glc 10-30% fs, s Mic ibdd w 1cm Mrls *Thallas* burrows extend 20cm down. Occ gwke or qtz granule, Sharks teeth

disconformity

Limestone 18.5 m 15-25cm bdd, lt gy, hd Mic bdd w 5-20mm Mrls at base and 1-4cm Mrls at top. Chert as continuous ribbons 10-20cm thick 25% at base decr sharply to 10% upward *Zoophycos* very abdt in a 1.5m band. Top 5m assoc w thicker Mrls contains abdt ech. spines, sponge spcs, and large benthic forams.

Limestone 8.4m 15-30cm-bdd, lt gy, pure, hd, Mic ibdd w 1-4cm shaley mrls. 10% chert as large blk nodules

Limestone 18m 3-10cm irreg-bdd, md gy, hd, Mic ibdd w 1-3mm shaley Mrls. 20% chert, dk gn as irregular nodules Med abdt *Chondrites* Rare horizons rich in large forams & ech spines ≤2mm?

Sandstone 5m mass. lt br-gy, hd, (calc), (glc), f gr Sst Sharp upper & lower contacts.

Siltstone / Sandstone [illegible] md-dk br-gy, (sft), [illegible] 2st. 1-10cm bds of md gy, [illegible] *pyrite*, f Sst [illegible] (40cm wide) [illegible] *Ecdysis*. Del cones ≤2m?

Structural data

PAGE 1 OF 3

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: DART STREAM (SOUTH FORK)

GEOLOGIST(S): JOHN C MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
C 30	C 42	–	

GRID REFERENCES: (metric)

map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 542 *	970	339 *	968	341 *

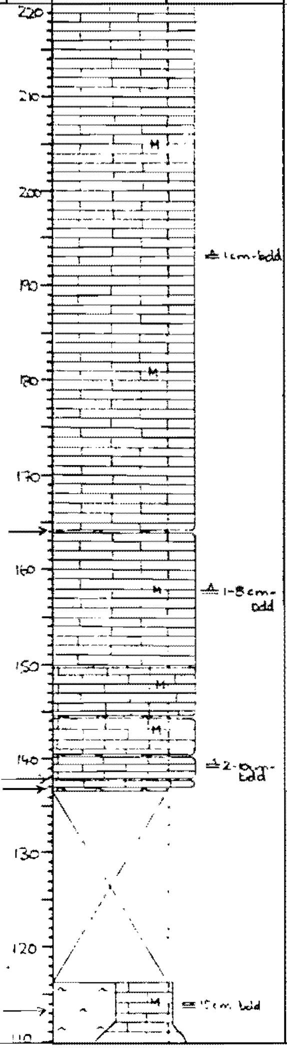
METHOD OF MEASUREMENT: TAPE AND COMPASS

DATE OF MEASUREMENT. 10 day 11 month 19 84 year

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Petrological data	Paleontological data	'F' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
Dp / Dh	MIDDLE LIMESTONE					220–140		≙ 1cm-bdd		
			030/F135 →	JM 42/19				≙ 1-8cm-bdd		
			Terebr.						Limestone 13m 2-10cm stylo-bdd, lt gy, hd, pure Mic Occ 30-40cm sft mrl Rare Terebr. fkts at base	
Dh / Cm			030/F144 →	JM 42/17				≙ 2-10cm-bdd		
	LOWER MARL		030/F53 →	JM 10/8		140–120			no exposure 20 m assume marl	
Cm / Dw			030/F52 →	JM 10/7		120–110		≡ 15cm bdd	Limestone 6.2m 15cm-bdd lt gy, hd, Mic ibdd w 7-15cm lt gy, sft Mrl.	



START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION:

SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: DART STREAM

GEOLOGIST(S): JOHN C MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
C	JM42	-	

DATE OF MEASUREMENT: 9 (day) 11 (month) 1984 (year)

GRID REFERENCES: (metric)

map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 S42 *	968	341 *	966	342 *

DRILLHOLES:
Has thickness been corrected for dip? YES , NO
Elevation of drillhole collar ______ metres a.s.l.

METHOD OF MEASUREMENT: TAPE AND COMPASS

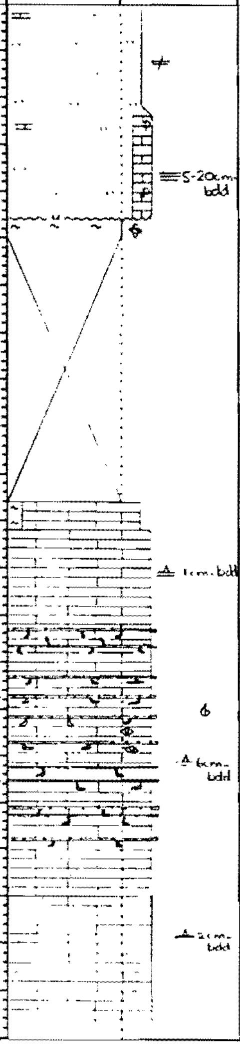
Stage: Lw / Ab; Ab / Ec

Formation: WAIMA SILTSTONE; WEKA PASS STONE; U. MARL; MIDDLE LIMESTONE; FELLS GREENSAND

Samples taken and results: Petrological data	Paleontological data	'f' number	Scale (metres)
	030/f121	JM 42/5	~309
	030/f128	JM 42/4	~307
	030/f132	JM 42/6	~277
	Pectin	JM 42/7, JM 42/8	~256
	030/f134	JM 42/9	~247

Scale (metres): 320, 310, 300, 290, 280, 270, 260, 250, 240, 230

GRAPHIC LOG / Additional graphic



Description — Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition

Limestone / Siltstone 30m + 5-20cm-bdd, md gy, hd, slc, f̂s, foram Packstone ibdd w lt gn-gy, (sft), calc, (slc), ±s Zd
No ld above 10m.

unconformity
Limestone 30m mass. lt gn-gy, sft, (carb), Mrl.
Poorly exposed May be faulted

no exposure

Limestone 3m 1cm-stylo bdd lt gy, hd Mic in 1m pkts ibdd w 10cm Mrl

Limestone 10·5m o/b

Limestone / Sandstone 22.7m 1-10cm stylo-bdd, lt gy, hd, Mic ibdd w 1-10cm md gn-gy hd, glc. 10% f̂, calc, sft, f̂ q'z Sst 1cm ⌀ Thallas. extending <40cm down into micrite below Sts have sharp bases but slightly grad tops ie glc extends up to 10cm above 1 small Pectin?
Up to 20% chert as small lent, pale bn or gn nods. in central zone only

Limestone 91m 1-2cm stylo-bdd, lt gy, hd, Mic No mrl
No chert No sand.

Structural data N

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: DEAD HORSE GULLY

GEOLOGIST(S): JOHN C MORRIS

NZMS 260 sheet: S2? — serial number: C ... 43A — horizon: – — remeasurement?

GRID REFERENCES: (metric) — map date: 19 S42 — BASE OF SECTION: easting 910, northing 290 — TOP OF SECTION: easting 909, northing 291

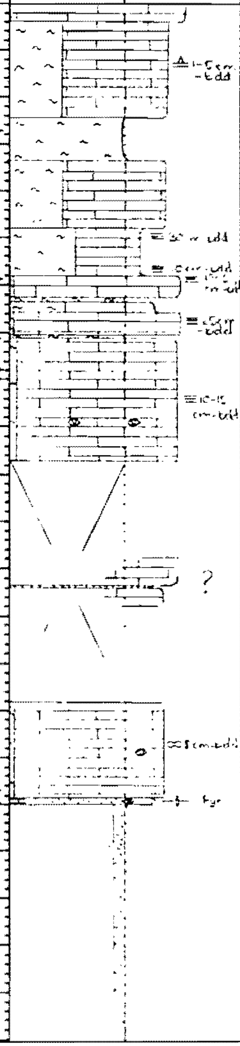
METHOD OF MEASUREMENT: TAPE AND COMPASS

DATE OF MEASUREMENT: 12 (day) 11 (month) 1984 (year)

DRILLHOLES: Has thickness been corrected for dip? YES, NO

Elevation of drillhole collar ______ metres a.s.l

Stage	Formation	Petrological data	Paleontological data	'f' number	Scale (metres)	Description
Dh		MIDDLE LIMESTONE		JM 43/7	110	Limestone 10m 1-5cm-thin-bdd, lt gy, (bd)-hd, Mic in 50-100cm pckts alt'n w 20-50cm Mrls
Dh / Dm	LOWER MARL			JM 43/6	100	Limestone 17m 10-30cm bdd, lt gy, hd, Mic bdd w 10-30cm lt gy, sft, Mrl. Grading up to mass mrl.
Dm / Dw					90	
	LOWER LIMESTONE			JM 43/5	80	Limestone 4.5m 10-15cm-bdd, lt gy, hd, Mrl bdd w 5mm-10cm Mrls 20cm mrl at base & 2.5 m below top. 25cm-bdd at base, 5-10cm-bdd at top
		542/f671 →		JM 43/4		
				JM 43/3	70	Limestone 12m 10-15cm-bdd, lt gy, hd, Mic bdd w 5mm Mrls. Layer of yell rim dk-gn cherts a few cm thick 4m above base. Mod abdt Planolites
					60	
						poor exposure 25.5m bedding appears to change from nodular to well bdd as shown
Dw / Dt		TEREDO LIMESTONE			50	
? / Mh	DEAD HILL FORMATION				40	
					30	Limestone 10m [illegible] (nod)-bdd, md gy, hd, [illegible] Mic [illegible] bdd w 2-3 mm [illegible] md gy sft Mrls 540% [illegible] nodules. Base 20cm contains few & [illegible] Sharp transition
		542/f670 → 542/f669 → CLAVERLEY SST	Thalassinoides, Teredo →	JM 43/2 JM 43/1		Sandstone 0.5m 20cm-bdd, lt gy, hd, glc 5-10%, calc, f Sst. Base 30cm pyr. Top 50cm 20-30% disseminated Pyr. Abdt Thalassinoides burrows; pyr in basal 30cm, [illegible] upper 30cm [illegible] Teredo tubes near top. 3-6cm lenses of lt gy, sft, glc 20%, [illegible] f Sst. 1cm layer of md-crs S [illegible], rnd-srnd, srt, Qtz 30cm above base [illegible] Rare [illegible] nodules [illegible] upper 15cm [illegible] brecciated [illegible] Arc [illegible]
	WHAREKIRI FORMATION				20	
					10	



PAGE 1 OF 1

START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: DEAD HORSE GULLY

GEOLOGIST(S): JOHN C MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM43A	–	

DATE OF MEASUREMENT: 12 (day) 11 (month) 19 84 (year)

GRID REFERENCES: (metric) 19 S42 (map date) *

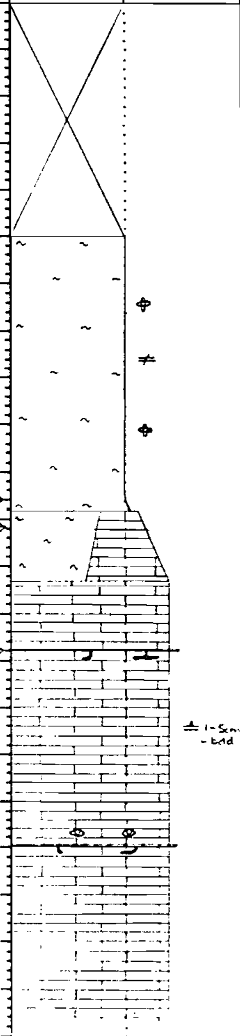
	easting	northing
BASE OF SECTION	909	291
TOP OF SECTION	908	292

DRILLHOLES: Has thickness been corrected for dip? YES , NO

METHOD OF MEASUREMENT: TAPE AND COMPASS

Elevation of drillhole collar ______ metres a.s.l

Stage	Formation	Petrological data	Paleontological data	'P' number	Disturbance	Scale (metres)	Description
						200 – 197	no exposure
?	UPPER MARL					197 – 167	Limestone 30m + mass, lt gn-gy, sft, (carb), Mrl. Abdl *Rugalites Zoophycos* present at least in top 5 m
				JM 43/10		167	
				JM 43/9		165 – 160	Limestone 7-3 m 1cm stylo-bdd, lt gy, hd Mic in 30cm packets, altn w 20cm mrls at base and 60cm Mrls at top.
Ah / Dp / Lc	MIDDLE LIMESTONE		*Thallasinoides*	JM 43/8		160 – 112	Limestone 45 5 m 1-5cm stylo-bdd, lt gy, hd, Mic No mrl. 2 1-6cm cnt, dk gn-gy glc, calc, srt, f qtz Sst Assoc *Thallasinoides* burrows extending 10cm below. Thin layer of 1-3cm cherts



Structural data ↑N

PAGE 1 OF __

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: MUZZLE STREAM

GEOLOGIST(S): JOHN C NORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?	DATE OF MEASUREMENT:
C	JM 43 B	-		12 (day) 11 (month) 1984 (year)

GRID REFERENCES: (metric)

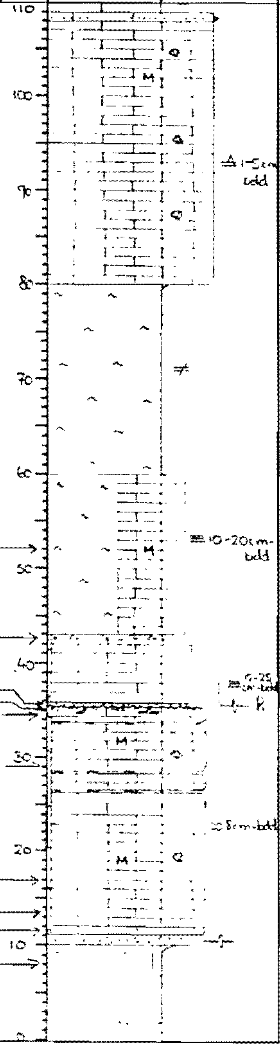
map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 S42 *	922	299 *	923	301 *

DRILLHOLES: Has thickness been corrected for dip? YES, NO

Elevation of drillhole collar ______ metres a.s.l.

METHOD OF MEASUREMENT: TAPE AND COMPASS

Stage	Formation	Petrological data	Paleontological data	'f' number	Scale (metres)	Description
Ab, Dp, Dp, Dh	MIDDLE LIMESTONE				110–80	Limestone 40m 1-5cm stylo-bdd, lt gy, hd, Mic No mrl <10% chert in anomalous thicker beds One (slc) Mic
Dh, Dm, Dm	LOWER MARL				80–60	Limestone 20m mass, H gy, sft, Mrl
				JM 43/13	60–46	Limestone 17m 10-20cm-bdd, lt gy-gy, hd, Mic ibdd w 10-20cm sft, Mrl
Dm, Lw	LOWER LST	030/F147	*Teichichnus*, *Zoophycos*, *Planolites*, *Teredo*	JM 43/19	46–39	Limestone 7.2m 15-25cm-bdd, lt gy, hd, Mic ibdd w 2-3mm sft Mrl 5% fS glc in basal 50cm Siliceous nodules and rare chert nodules Intensely bioturbated *Teichichnus*, *Zoophycos*, *Planolites*, Rare *Thalassinoides*
Dw		TEREDO LIMESTONE 542/F675 030/F139 542/F674	*Thalassinoides*	JM 43/17 JM 43/16 JM 43/15	38	Sandstone 16cm md gy-gy, hd, calc, glc. 20% fS, mic f Sst Basal 4cm poorly cemented & sft Glc decr to 5-10% in upper 6cm Rare qtz-qtz & phos grains
Dt, Mn	MEAD HILL FORMATION			JM 43/14 JM 43/12 JM 43/11 JM 43/10	38–12	Limestone 24.2m 8cm mod bdd, md gy, hd, sil Mic ibdd w 2-3 mm lt-md gy sft Mrls, 10% chert nods Occ concr 2-3cm mrls at position shown Upper 3cm contains 1-3cm Ø *Thalassinoides* burrows of gd with glc sst from above 8cm concretionary mrl 15cm below top
		542/F676	*Thalassinoides*			
	WOOLSHED FORMATION	WAVERLEY SST 030/F119		JM 43/20	12–0	Sandstone 11m mass, lt gy, hd, glc, calc f Sst Basal [illegible] "bdd" & md "1-5cm bdd" [illegible] 50cm Relatively sharp but conformable [illegible] Teredo [illegible] *Thalassinoides* [illegible]



Structural data N

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START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET, EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: MUZZLE STREAM

GEOLOGIST(S): John C Morris

030 — NZMS 260 sheet | C JM 438 — serial number | – — horizon | remeasurement?

GRID REFERENCES: (metric) 19 S42 (map date) * BASE OF SECTION: 932 (easting) 310 (northing) * TOP OF SECTION: 931 (easting) 311 (northing) *

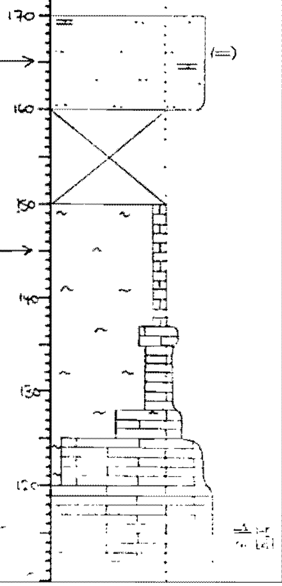
METHOD OF MEASUREMENT: TAPE AND COMPASS

DATE OF MEASUREMENT: 12 (day) 11 (month) 1986 (year)

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ______ metres a.s

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'P' number	Disturb-ance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data ↑N
Lw	WAIMA SILTSTONE		030/F46 →	JM 11/1 →		170		(=)	Siltstone 10m+ mass. md gy, hd-hd, calc, fs Z.	
						160			10m no exposure	
Ab	UPPER MARL		030/F45 →	JM 11/2 →		150, 140, 130			Limestone 30m 5cm-bdd, lt gy, hd Mic; bdd w 1mm-1m lt gy, sft, Mrls Marls thickening upwards	
	MIDDLE LIMESTONE					120				



MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

NZMS 260 sheet	serial number	horizon	remeasurement?
	c JM 50 A	–	

DATE OF MEASUREMENT: 14/29) 3/11) 1984 (day, month, year)

LOCALITY: BLUFF STREAM (LOWER)

GRID REFERENCES: (metric)

map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 S42	844	255	823	255

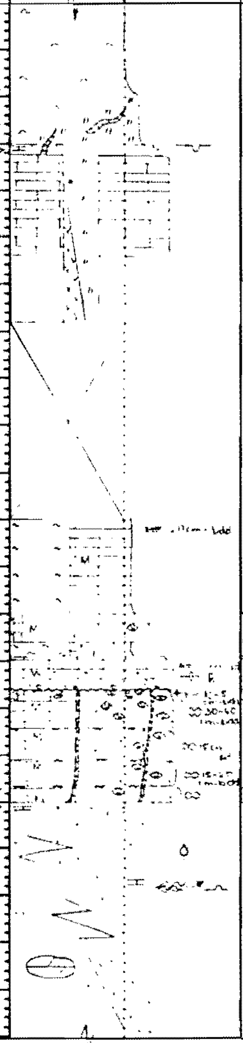
DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ______ metres a.s.l.

GEOLOGIST(S): JOHN C NORRIS

METHOD OF MEASUREMENT: TAPE AND COMPASS

Stage	Formation	Samples taken and results: Petrological data	Samples taken and results: Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
Ak						110			Limestone	
Ab	UPPER MARL		030/f124	JM 50/26		100			Tuff	
		GRASS SEED VOLCANICS		JM 50/27						
				JM 50/24 25					Sandstone	
	MIDDLE LST					90				
									Limestone	
				JM 50/22		80				
									Limestone	
?						70				
									Limestone	
						60			Limestone	
									Limestone	
						50			Limestone	
		LOWER LIMESTONE		JM 5/4						
Dm		TEREDO LIMESTONE	Thalassinoides			40			Limestone	
Mh	MEAD HILL FORMATION								Limestone	
						30				
				JM 5/2						
	CLAVERLEY SANDSTONE		030/f55	JM 5/1		20			Sandstone 0-50m mass (w faint lam),	
			542/f511			10				
	WOOLSHED FORMATION					0				



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START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ________ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: BLUFF STREAM (UPPER)

GEOLOGIST(S): JOHN C MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JMSOB	-	

DATE OF MEASUREMENT: 28 (day) 11 (month) 1984 (year)

GRID REFERENCES: (metric)

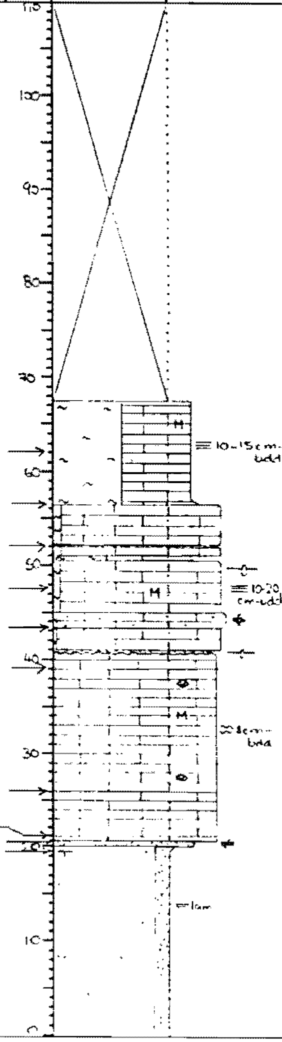
map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 342 *	878	275 *	877	276 *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

METHOD OF MEASUREMENT: TAPE AND COMPASS

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)
	LOWER MARL			JM 50/12		65
Dm / Dw			*Teredo* 030/f 146	JM 50/10, 11		57
	LOWER LIMESTONE		030/f 148	JM 50/9		53
				JM 50/8		48
Dw			Abundant *Zoophycos*	JM 50/7		44
		KAIKOURA GREENSAND	*Thalassinoides*	JM 50/6		41
	MEAD HILL FORMATION		030/f 142	JM 50/5		26
			Rhizo corallinoides 030/f 37	JM 50/4		22
		WAVERLEY SST	? *Teredo*	JM 50/2,3 / JM 50/1		20
	WOOLSHED FORMATION					



Description — Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition

no exposure 56 m assume marl

Limestone 11m 10-15cm-bdd, Hgy, hd, Mic bdd w 10-15 cm Hgy sft. Mrl. Basal bed has clusters of *Teredo* tubes. Most flattened < 5mm ø & 6 cm long.

Limestone 15.5m a/b but no glc except in rare burrows at an anomalous horizon. Marls ave 2-3cm w anomalous 5-15 cm beds

Limestone 1.8m a/b but 1-2% glc fS Occ rare crs S phos grains *Zoophycos* [illegible]

Limestone 2.3m 10-20cm-bdd Hgy, hd, Mic bdd w 5mm mrls Few & [illegible] chert rinds

?Sandstone ?10cm poor exposure.

unconformity

Limestone 20.1 m 5-10cm [illegible]-bdd [illegible] [illegible], hd, sil, Mic bdd w 2-5mm mrls Very low [illegible] 10% chert Occ 5cm marls [illegible] poorly [illegible]. [illegible] 100cm above base

Sandstone 0.5 m mass, lt bn-gy, non-calc, (hd)-hd, glc-5-10% mS, srt f Sst. Rare gran rnd cwhc & [illegible] Pres [illegible] Rare 1cm ø *Thalassinoides*. Becomes [illegible] - calc in upper 20cm. [illegible] bedding . upper 15cm (5 cm-bdd). Sharp upper & lower contacts. [illegible] *Teredo* [illegible] & shark teeth at [illegible].

Structural data ↑N

PAGE 1 OF 2

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: BLUFF STREAM (UPPER)

GEOLOGIST(S): JOHN C MORRIS

NZMS 260 sheet: C 3M1 20b | serial number: – | horizon | remeasurement?

GRID REFERENCES (metric): 19 S42 (map date) * BASE OF SECTION: 877 (easting) 276 (northing) * TOP OF SECTION: 277 (easting) 279 (northing) *

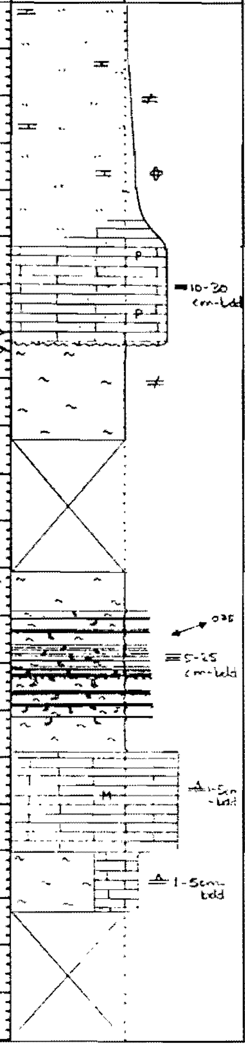
METHOD OF MEASUREMENT: TAPE AND COMPASS

DATE OF MEASUREMENT: 28 (day) 11 (month) 1984 (year)

DRILLHOLES: Has thickness been corrected for dip? YES, NO

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Petrological data	Paleontological data	'f' number	Scale (metres)	Description
	WAIMEA SILTSTONE		Zoophycos	JM 50/22	220–200	Siltstone 25m mass, lt gy, hd, (glc), ŁS Zst Abtt Zoophycos Arbitrary transition from Lst below
Lw	WEKA PASS STONE	030/f69; 030/F129		JM 50/21; JM 50/20	190	Limestone 10m 10-30 cm-bdd, lt gy – wh, hd-bd, (glc): 4-5% ſs Forom Pist Rare grn, <5% Phos grains. Thin, Mrl ibds. Base poorly exposed.
						unconformity
Ar					180	Limestone 10m mass, lt-mdgn-gy, sft, ſss, (glc): <1% ſs, (carb), Mrl.
Ak					170	no exposure 14m
			Thalassinoides; 030/F126	JM 50/19; JM 50/18; JM 50/17	160–150	Limestone / Sandstone 19m mass, lt-gy, sft, ſss, (glc) 2-3% ſs, (s) Mrl with 5-25cm, md gn-gy, hd-bd calc, sft, rnd, glc 5-10% ſ, ms, micro qtz Sst. Sst fluted on base and intensely burrowed by 1cm ø Thalassinoides. Sst of ls burrows to a depth of 20cm in underlying mrl
Ab; Dp					140	Limestone 11m 1-5cm stylo-bdd, lt gn-gy, hd pure M'c No mrl
Df; Dh		030/f?		JM 50/16	130	Limestone 5m 1-5cm stylo-bdd, lt gn-gy, hd M'c in 10-50cm pockets in w 20-50cm lt gy, sft Mrl.
					120–110	



START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: BLUFF RIVER

GEOLOGIST(S): JOHN C MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM 52	-	

DATE OF MEASUREMENT: 30 (day) 11 (month) 19 84 (year)

GRID REFERENCES: (metric)

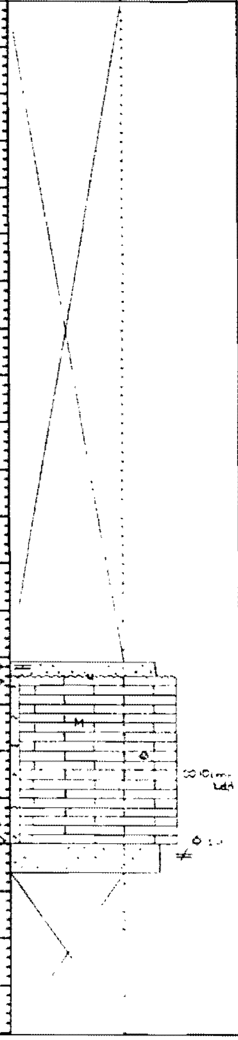
map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 S42 *	239	246 *	239	246 *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ______ metres a.s.l.

METHOD OF MEASUREMENT: TAPE AND COMPASS

Stage	Formation	Samples taken and results: Petrological data	Samples taken and results: Paleontological data	'P' number	Disturb-ance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
	Lower ? Marl ?		S42, F664			50			Siltstone [illegible]	
Dw		TEREDO LIMESTONE	030/F142	JM 52/5		40			[illegible]	
Mr			S42, F654, 655	JM 52/4					Limestone [illegible]	
	MEAD HILL FORMATION		030/F137	JM 52/3		30		50-100 mm bdd		
		CLAVERLEY SST		JM 52/1, 2		20			Sandstone [illegible]	
						10				



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MEASURED SECTION DETAIL SHEET

REGION: ____________ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: WOODSIDE CREEK , LWR GORGE

GEOLOGIST(S): JC MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM 104	–	

DATE OF MEASUREMENT: 27 (day) 1 (month) 1985 (year)

GRID REFERENCES: (metric)

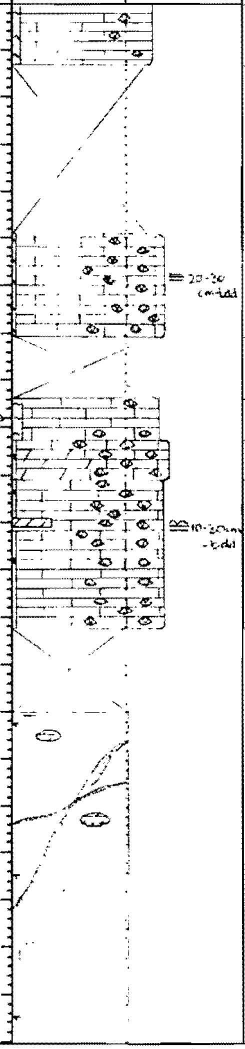
map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 536 *	334	478 *	335	478 *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ______ metres a.s.l.

METHOD OF MEASUREMENT: TAPE AND COMPASS

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
						110				
									no exposure 17.5 m	
						100				
						90				
									Limestone 10.8 m 20-30 cm bdd lt gn-gy, hd Mic bd w 1 cm marls [20-40]% chert nodules Some large nodules	
						80		20-30 cm bdd		
									no exposure 6.5 m scree slope	
						70				
			JM 104/1						Limestone 4.3 m 10-30 cm bdd lt-md gn-gy, hd ... Mic ... w 1-5 cm lt gy ... mrls 15-20% chert nods	
									Limestone 4.1 m 20-30 cm bdd md gy, hd-hd, ... Mic ... 5-10 mm ... 60% ... nodules 40-50% ... [illegible]	
						60			Limestone 5.8 m 10-20 cm bdd md gy, hd ..., non-calc Mic ... 1-5 mm ... 50% nodular chert No detrital	
								10-30 cm bdd		
Mh	MEAD HILL FORMATION					50				
									no exposure 5.6 m possibly faulted	
						40				
									Siltstone / Mudstone >25 m 1-2 cm bdd and ... calc, ... Some ... No apparent bioturb ... w 2-5 mm ... 1-2 cm wide low angle clastic dk ... of lt gy ...	
						30				
	WOODSIDE FORMATION					20				
						10				
						0				



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START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ______

SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: WOODSIDE CREEK, LWR GORGE

GEOLOGIST(S): J MORRIS

NZMS 260 sheet: C | serial number: JM 104 | horizon: – | remeasurement?

DATE OF MEASUREMENT: 27 (day) 1 (month) 1985 (year)

GRID REFERENCES: (metric) 19 (map) 536 (date) *

BASE OF SECTION: 335 (easting) 478 (northing) *

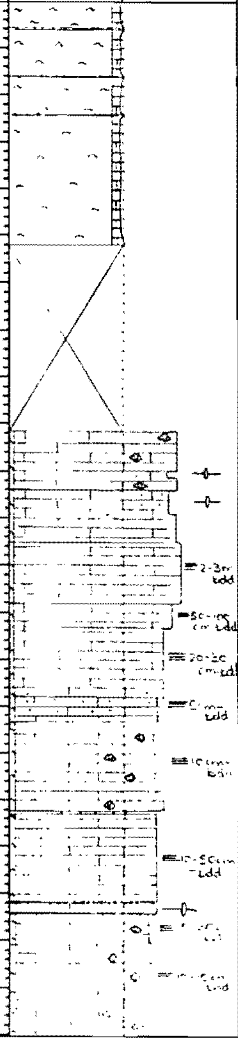
TOP OF SECTION: 336 (easting) 478 (northing) *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

METHOD OF MEASUREMENT: TAPE AND COMPASS

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
	LOWER MARL					220, 210, 200				
						190, 180			not crossed ~20m probably faulted	
Dw			Zones of most intense burrowing						Limestone 6.2m a/b but burrows are stuffed and connect with vertical "sponge"-like structures. Most intense burrowing in md-red Mic with sandy detritus	
Dt				JM104/5		170			Limestone 5.6m 1-2 m-bdd, lt pk, hd, Mic std w thin mrls, No chert intense burrowing (by Thalass??) Most intense burrowing in 2.5 m bed at top	
	MEAD HILL FORMATION					160		2-3m bdd	Limestone 6.4m a/b but 2-3m-bdd	
								50-100 cm bdd	Limestone 2.7m a/b but 50-100cm bdd	
						150		20-30 cm bdd	Limestone 6.6m a/b but no sand bedding 20-30cm Thin rd Mrls.	
			First appearance of [illegible]	JM104/4				bdd	Limestone 3.7m a/b but lt pk-gy with f S sand, glc, forams spicules, conc at base of beds and 45cm	
				JM104/3		140		10cm bdd	Limestone 9.4m 10cm-bdd, [illegible]-gy hd, (lam), Mic std w 5-8mm [illegible] Mrls 10% chert as thin black bands. Rare small Zoophycos [illegible] at top.	
Dt									Shale / Limestone 25cm 1-5cm-bdd dk-gy – dk-gy, hd, [illegible] Shale & Mic. Basal 2cm. [illegible] limonite stained	
Mh						130		10-50cm bdd	Limestone 10.7 m 10-90 cm-bdd (ave 20cm-bdd), lt gy, hd, Mic std w 5-20mm lt gy [illegible], sft Mrls. No chert. Low bioturb – a few Planolites o [illegible] [illegible] [illegible], [illegible] sandy, [illegible] most of [illegible] burrows ≤2cm [illegible]	
				JM104/2		120			Limestone [illegible] [illegible] Mic [illegible] stained	
								bdd	Limestone [illegible]	
						110				



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MEASURED SECTION DETAIL SHEET

REGION: ____ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: Woodside Creek (Lower Gorge)

GEOLOGIST(S): J. Morris

NZMS 260 sheet	serial number	horizon	remeasurement?
	C J41/C4	-	

GRID REFERENCES (metric): 19 S56 (map date) * BASE OF SECTION: 336 (easting) 478 (northing) * TOP OF SECTION: 336 (easting) 478 (northing) *

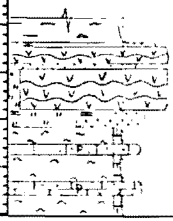
METHOD OF MEASUREMENT: Tape and compass

DATE OF MEASUREMENT: 27 (day) 1 (month) 1985 (year)

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ____ metres a.s.l.

Stage	Formation	Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
									Siltstone 0.3m dk gn-gy, hd, calc, f S zd	
									Basalt 1.7m dk gy, hd, amyg, basalt	
						200			Sandstone 50cm md br-gy, (hd)-(sft) calc, f Sst	
	Awaleur? Formation								Basalt / Tuff 1-2m dk-gy, hd, amyg, basalt flows ibd w 5-10cm bdd md gy tuff	
Dh									Sandstone Tuff 5-10cm lt gy, (hd), calc, (sft), f Sst ibd w 5-10cm bdd md-dk gy (hd) calc f tuff	
Dm						220			Limestone 30cm mass md gn-gy, sft, (cork) Mrl w 10cm lt gy ... Mrl ... md gn-gy, hd, (mrl) red ... Fmn ... 5-10cm bed ... at top	
	Limestone Mbr					220				



START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: SEYMOUR STREAM

GEOLOGIST(S): J.C. MORRIS

031	C JM 121	–	
NZMS 260 sheet	serial number	horizon	remeasurement?

DATE OF MEASUREMENT: 18 (day) 02 (month) 1985 (year)

GRID REFERENCES: (metric)

19 S41	708	125	707	125
map date	easting (BASE OF SECTION)	northing (BASE OF SECTION)	easting (TOP OF SECTION)	northing (TOP OF SECTION)

DRILLHOLES: Has thickness been corrected for dip? YES , NO

METHOD OF MEASUREMENT: TAPE AND COMPASS

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Petrological data	Paleontological data	'P' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data
	WEKA PASS STONE		Broken shell fragments.			110		= 20-50 cm-bdd	Limestone / Tuff / Siltstone 50cm 20-50cm-bdd ...	
Lwh	COOKSON VOLCANICS			JM 121/3, JM 121/2		100		∀, f, ≠	Tuff 10m massive ... basaltic Tuff. Abdt ... fragments ... at top as limestone enters. ... disconformity ... Limestone 10m massive ...	
	FELLS GREENSAND		Ichnogenus *Thalassinoides* sp.	JM 121/1		80		= 5-30cm-bdd	Limestone / Sandstone ... *Thalassinoides* ...	
At	UPPER MARL					70		≠	Limestone 10m ...	
Dp	MIDDLE LIMESTONE					60		= ...cm-bdd	Limestone 5m ...-bdd ... intervals	
Ch	LOWER MARL		Pteropods ... well preserved ...	JM 120/1, JM 122/4, JM 122/3		50, 40		∀, ≠	Limestone 5m ...	
Mh	CLAVERLEY SANDSTONE		Possible ... not ... but probably transported	JM 122/1&2		30		☆, = ...cm-bdd	Sandstone 20m ...	
Mh	...					20, 10			Gypsum 30cm ... Gypsum. Siltstone / Sandstone ... bdd ...	

PAGE 1 OF 1

START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF ... MEASURED ... TO ... ON ... BACK OF THIS SHEET

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: THE FELL

GEOLOGIST(S): J. C. MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM123	–	

DATE OF MEASUREMENT: 20 (day) 2 (month) 19 85 (year)

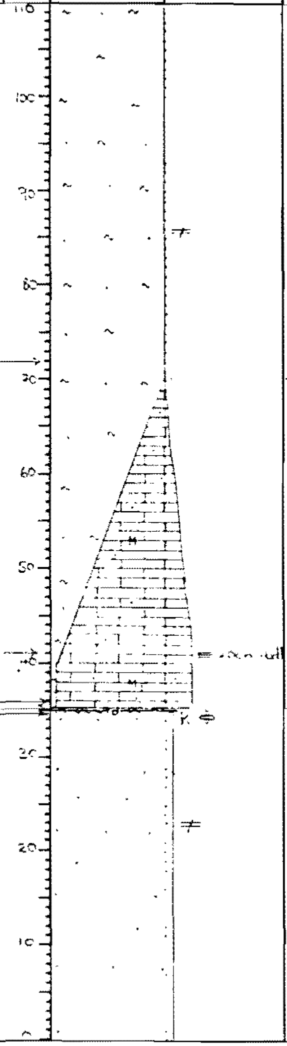
GRID REFERENCES: (metric) 19 S41 (map date) * BASE OF SECTION 697 (easting) 109 (northing) * TOP OF SECTION 698 (easting) 111 (northing) *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

METHOD OF MEASUREMENT: TAPE AND COMPASS

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data (N)
	UPPER MARL					110			Limestone 20m mass, hd gn-gy, sft, (glc 3-5% f-fS), (s Mn) No evidence of set beds	
Ab / Dp	UPPER MARL	031/f145 →		JM 123/1		100 – 70				
	MIDDLE LIMESTONE					70			Limestone 35m 20cm-bdd, lt gn-gy, hd, (glc 3-5% fS) Mic bdd w 10mm lt gn-gy, sft (glc) Mn. Basal 5m contains abdt cse lithics grains < cse S. Glc 2% of base incr to 5% 15m above base. Relief on bottom of basal [illegible] demarcated by *Thalassinoides* burrows	
	MIDDLE LIMESTONE			JM 123/5		40		20cm wall	Limestone [illegible] mass, lt gn-gy, [illegible] [illegible] *Thalassinoides* burrows [illegible] filled [illegible]	
Dh / Mh		031/f232 →	Small shells, teeth *Teredo* & *Thalassinoides*	JM 123/4, JM 123/3, JM 123/2					Sandstone 18m mass, md gn-gy, [illegible], [illegible] 20% [illegible] f. Glc incr to > 30% below [illegible] *Teredo* tubes 20cm from top [illegible] [illegible] pless. Upper surface [illegible] [illegible] *Thalassinoides* [illegible] < 10cm below Fossil bed	
	[illegible]					30 – 0				



START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: THE FELL

GEOLOGIST(S): J. C. MORRIS

031	C 3M123	–		
NZMS 260 sheet	*serial number*	*horizon*	*remeasurement?*	

DATE OF MEASUREMENT: 20 *day* 2 *month* 1985 *year*

GRID REFERENCES: (metric)

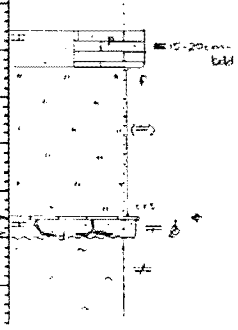
	BASE OF SECTION		TOP OF SECTION	
19	698	111	698	111
map date	*easting*	*northing*	*easting*	*northing*

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ______ *metres a.s.l.*

METHOD OF MEASUREMENT: TAPE AND COMPASS

Stage	Formation	Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data
									no exposure	
						140		15-20cm bdd	Limestone Siltstone 4m 15-30cm-bdd [illegible] Foram Pst [illegible] w 5-20cm-bdd [illegible]	
									Tuff 16m mass. to faintly bdd, [illegible] basaltic Tuff. Fining up from [illegible] at base to [illegible] at top. [illegible] beds. Sharp basal contact	
						130			Limestone 15cm [illegible] burrows extend down up to 1m in underlying [illegible] into [illegible]	
									Sandstone 2m mass., [illegible] (bd), calc, [illegible] material [illegible] fragments	
Lwh		031/f210	Fragilaria [illegible]	JM 123/7 JM 123/6		120			~~~~ disconformity ~~~~ Base [illegible]	
Ab-Ar										



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MEASURED SECTION DETAIL SHEET

REGION: ____________ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: WALLOW CREEK

GEOLOGIST(S): J. C. MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
	CJM 125	–	

GRID REFERENCES: (metric)

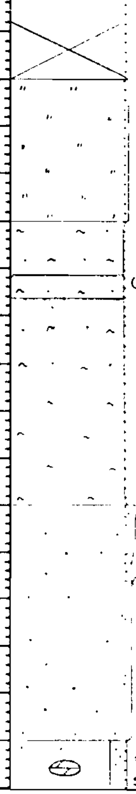
map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 S42	662	095	668	095

METHOD OF MEASUREMENT: TAPE AND COMPASS

DATE OF MEASUREMENT: 21 (day) 2 (month) 1985 (year)

DRILLHOLES: Has thickness been corrected for dip? YES, NO

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
									no exposure	
Lwh	Cookson Volcanics					70		≠	Tuff 15m mass., md rd-bn, calc, sft, fs basaltic Tuff Frlu exposed. Basal contact obscure	
Ab / At	Upper Marl			JM 125/3 →		60, 50		(=), ≠	Limestone 30m mass., lt gn-gy, sft, glc <5% fs, (s) Mcl Pure at base, becoming ± up A few 5cm, (hd), glc, fs Zst 5-10m below top. Sharp basal contact	
Dc / ?	Lower Marl					40				
Lh / Dm / Dw	Tepito Limestone			JM 125/2, JM 125/1 →		30, 20, 10		≠	Greensand 25m md gn, sft (calc) glc 50-60% amS Grsd. Becomes md gn-gy sft, calc, glc 20% fS, fSst in top 5m. 30cm more cemented Frlu gn pebbly sst 20cm below top. Clasts well rnd, calc & mfe	
Mr		Wangaloa Formation				0		= Sharp wkd, Sul	Siltstone ... Sandstone-bdd, md gy sft ... bdd w. occ hd ... fSst ... few ...	

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START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: GRASS SEED STREAM

GEOLOGIST(S): JOHN C MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM 127	-	

DATE OF MEASUREMENT: 22 (day) 2 (month) 1985 (year)

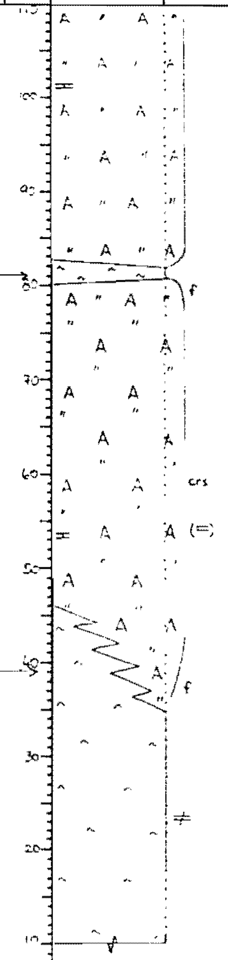
GRID REFERENCES: (metric)

map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 S42	830	192	827	188

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ______ metres a.s.

METHOD OF MEASUREMENT: TAPE AND COMPASS

Stage	Formation	Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description (Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition)	Structural data N
	GRASS SEED VOLCANICS		030/F122, F514, F515	2K 63/1		80		f	Tuff / Agglomerate 25m [illegible] ... This unit is apparently [illegible] to a thick sequence [illegible] 300m [illegible] with no [illegible] break between sections. The [illegible] volcanics in the adjacent [illegible] are [illegible] thick [illegible] over [illegible] a 30m lens of the thick tuff	
						60		crs		
Ab	UPPER MARL		030/F68, F..., F514	2K 63/...		40		f	[illegible] 25m [illegible] Upper [illegible] interfingers [illegible]	
						10				

PAGE ___ OF ___

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: GRASS SEEL STREAM

GEOLOGIST(S): JOHN C MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
	C JM127	–	

GRID REFERENCES: (metric)

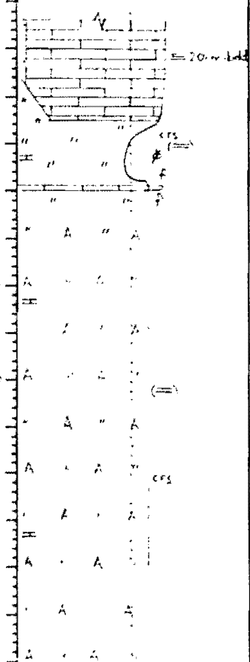
map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19	227	128	225	125

METHOD OF MEASUREMENT: TAPE AND COMPASS

DATE OF MEASUREMENT: 22 (day) 2 (month) 1985 (year)

DRILLHOLES:
Has thickness been corrected for dip? YES , NO
Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'f' number	Disturb-ance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data
									not exposed	
	[illegible]					170		= 20cm bdd	Limestone [illegible] 20 cm bdd [illegible]	
Lwh	[illegible]					160			Tuff [illegible]	
Ab						150			Limestone [illegible]	
						140		(=)		
						130				
						120				



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MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: LIMESTONE HILL

GEOLOGIST(S): J MORRIS

NZMS 260 sheet	serial number	horizon	remeasurement?
C	JM 128	–	

DATE OF MEASUREMENT: 23 (day) 2 (month) 1985 (year)

GRID REFERENCES: (metric)

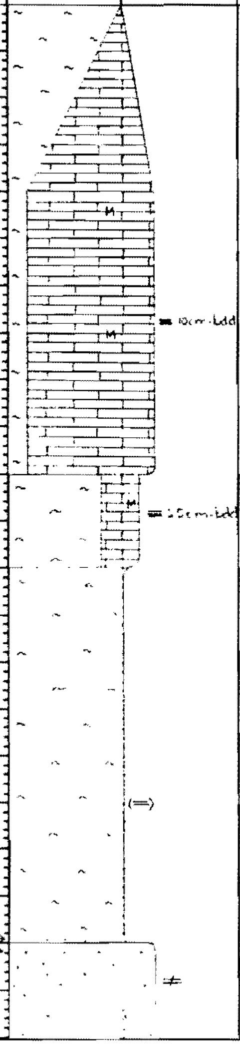
map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 542	813	168	815	170

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ______ metres a.s.l.

METHOD OF MEASUREMENT: TAPE AND COMPASS

Stage	Formation	Petrological data	Paleontological data	'f' number	Scale (metres)	Additional graphic	Description
	UPPER MARL				110		Limestone [illegible]
Ab			020/f8 →		100		
Dp	MIDDLE LIMESTONE				90		
					80	10cm bdd	
					70		
Dp			030/f67 →	JM 128/5 →			
Dh			020/f66 → 242/f522 →	JM 128/4 →	60	10cm bdd	Limestone [illegible]
					50		Limestone [illegible]
	LOWER MARL				40		
					30	(=)	
Lh					20		
Lm			030/f65 →	JM 128/3 →			
	TERES LIMESTONE	030/f64 → 030/f62 →	*Teredo* tubes → 030/f2 → 030/f1 →	JM 128/2 JM 128/1 →		≠	Sandstone [illegible] *Teredo* tubes [illegible]



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START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: 1 cm : 1 m (1:100) 1 cm : 10 m (1 : 1000) 1 cm : 50 m (1 : 5000)

LOCALITY: LIMESTONE HILL

GEOLOGIST(S): JOHN C MORRIS

NZMS 260 sheet: ______ | serial number: C JM 128 | horizon: – | remeasurement?

DATE OF MEASUREMENT: 23 (day) 2 (month) 1985 (year)

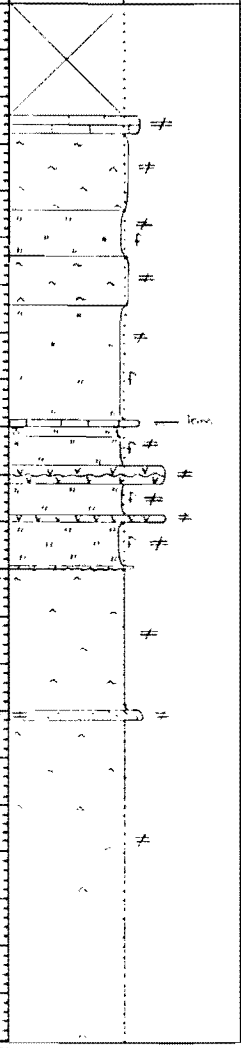
GRID REFERENCES: (metric) 19 842 (map date) * BASE OF SECTION: 815 (easting) 170 (northing) * TOP OF SECTION: 816 (easting) 168 (northing) *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

METHOD OF MEASUREMENT: TAPE AND COMPASS

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Petrological data	Paleontological data	'f' number	Disturb-ance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description	Structural data
						220				
						210			No exposure	
				JM 128/12					Limestone 2m mass, f-gr, hd, calc algal-bryozoan-foram Pkst	
			030/f76	JM 128/11					Limestone 9m a/b	
						200			Tuff 5m a/b	
				JM 128/10					Limestone 5m mass, lt gn-gy (sft) (rd), calc, Marl	
						190			Tuff 2m a/b	
	COOKSON VOLCANICS					180			Limestone 10cm lam, lt gy, md, calc) algal-bry-foram Pkst 10cm tuff 10cm above base. Small rip-ups of tuff near base	
			Coralline algae & bryozoa	JM 128/9					Tuff 4m a/b upper 1m becomes md gy tuff mst	
						170			Basalt 2m a/b	
									Tuff 3.3m a/b non-fossiliferous	
									Basalt 70cm mass, blk, rd, (vesic). Basalt flow	
Lwh			Pectins, gastropods, teeth 030/f149, f7	JM 128/8					Tuff 4.5m mass, md rd-brn, slt, calc, fossiliferous f-ms Las Tuff macrofoss ≤ 45mm incl pectins, gast teeth, fish bones.	
Ab			030/f127	JM 128/7		160			Sandstone 45cm mass, md gy, calc, glc ≤ 7%, f-m sst disconformity base ≤ 5 grains	
									Limestone 6m a/b Section shortly on sst. No burrow bz. Upper contact prob diachronous	
						150				
				JM 128/6					Limestone 1m mass, lt md gy, calc glc sst f gls	
						140			Limestone 3m mass, f gr, gy, sft, calc, Mrl	
						130				
	AMURI MARL					120				
						110				



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START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET, EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

APPENDIX V: Sample Numbers And Locations

SAMPLE NO.	UNIVERSITY OF CANTERBURY NO.	LOCATION	NZMS 1 GRID REFERENCE	
JM 1/2	12208	Kaikoura Pensla	S49	964887
JM 1/3C	12209	Kaikoura Pensla	S49	964887
JM 1/4	12210	Kaikoura Pensla	S49	964887
JM 1/5	12211	Kaikoura Pensla	S49	966886
JM 1/7	12212	Kaikoura Pensla	S49	966886
JM 1/8	12213	Kaikoura Pensla	S49	966886
JM 2/9	12214	Kaikoura Pensla	S49	983899
JM 3/2	12215	Oaro	S56	802773
JM 3/3	12216	Oaro	S56	802774
JM 3/6	12217	Oaro	S56	802775
JM 3/7	12218	Oaro	S56	802775
JM 4/1	12219	Kaikoura Pensla	S49	978898
JM 4/2	12220	Kaikoura Pensla	S49	978898
JM 4/3	12221	Kaikoura Pensla	S49	978898
JM 4/4	12222	Kaikoura Pensla	S49	978897
JM 4/5	12223	Kaikoura Pensla	S49	978897
JM 4/6	12224	Kaikoura Pensla	S49	978897
JM 5/1	12225	Haumuri Bluff	S56	812733
JM 6/4	12226	Conway River Mth	S55	756668
JM 7/3	12227	Cribb Creek	S49	805943
JM 7/4	12228	Cribb Creek	S49	806942
JM 10/1	12229	Dart Stream	S42	973340
JM 10/3	12230	Dart Stream	S42	973340
JM 10/4	12231	Dart Stream	S42	973340
JM 10/7	12232	Dart Stream	S42	970339
JM 10/8	12233	Dart Stream	S42	970339
JM 12/1	12234	Bluff Stm (lower)	S42	884245
JM 12/2	12235	Bluff Stm (lower)	S42	884245
JM 12/3	12236	Bluff Stm (lower)	S42	884245
JM 15/2	12237	Haumuri Bluff	S56	812732
JM 15/3	12238	Haumuri Bluff	S56	812732
JM 15/6	12239	Haumuri Bluff	S56	812732
JM 15/7	12240	Haumuri Bluff	S56	813733
JM 15/8	12241	Haumuri Bluff	S56	813733
JM 18/1	12242	Mt Alexander	S42	072158
JM 18/2	12243	Mt Alexander	S42	073157
JM 18/3	12244	Mt Alexander	S42	073157
JM 18/4	12245	Mt Alexander	S42	073157
JM 18/6	12246	Mt Alexander	S42	073157
JM 19/7	12247	Mororimu Stm	S42	141134
JM 19/12	12248	Mororimu Stm	S42	141134
JM 20/2	12249	Puhi Puhi River	S49	021071
JM 20/3	12250	Puhi Puhi River	S49	021071
JM 20/4	12251	Puhi Puhi River	S49	021071
JM 20/5	12252	Puhi Puhi River	S49	021071
JM 20/10	12253	Puhi Puhi River	S49	021071
JM 20/15	12254	Puhi Puhi River	S49	021071
JM 20/18	12255	Puhi Puhi River	S49	021071
JM 25/7	12256	Puhi Puhi River	S42	035106
JM 25/8	12257	Puhi Puhi River	S42	035106
JM 25/9	12258	Puhi Puhi River	S42	035106
JM 25/11	12259	Puhi Puhi River	S42	035105
JM 25/13	12260	Puhi Puhi River	S42	035105
JM 30/5	12261	Mead Stream	S35	086452
JM 30/14	12262	Mead Stream	S35	083448

APPENDIX V: Sample Numbers And Locations

SAMPLE NO.	UNIVERSITY OF CANTERBURY NO.	LOCATION	NZMS 1 GRID REFERENCE	
JM 30/21	12263	Mead Stream	S35	082448
JM 30/22	12264	Mead Stream	S35	081448
JM 30/24	12265	Mead Stream	S35	080448
JM 30/25	12266	Mead Stream	S35	078448
JM 30/27	12267	Mead Stream	S35	078448
JM 30/30	12268	Mead Stream	S35	078448
JM 30/32	12269	Mead Stream	S35	077449
JM 30/33	12270	Mead Stream	S35	077449
JM 30/35	12271	Mead Stream	S35	077449
JM 30/36	12272	Mead Stream	S35	076450
JM 30/37	12273	Mead Stream	S35	076450
JM 30/40	12274	Mead Stream	S35	075451
JM 30/41	12275	Mead Stream	S35	075452
JM 30/42	12276	Mead Stream	S35	075452
JM 32/1	12277	Dee Stream	S35	022401
JM 40/12	12278	Branch Stream	S42	008375
JM 40/13	12279	Branch Stream	S42	007376
JM 40/21	12280	Branch Stream	S42	006378
JM 40/22	12281	Branch Stream	S42	006378
JM 40/27	12282	Branch Stream	S42	006378
JM 40/28	12283	Branch Stream	S42	006378
JM 41/1	12284	Whisky Stream	S42	997362
JM 41/4	12285	Whisky Stream	S42	996362
JM 41/5	12286	Whisky Stream	S42	996362
JM 41/6	12287	Whisky Stream	S42	995363
JM 42/1	12288	Dart Stream	S42	970339
JM 42/3	12289	Dart Stream	S42	973340
JM 42/4	12290	Dart Stream	S42	966342
JM 42/5	12291	Dart Stream	S42	966342
JM 42/6	12292	Dart Stream	S42	968341
JM 42/7	12293	Dart Stream	S42	968341
JM 42/9	12294	Dart Stream	S42	968341
JM 42/12	12295	Dart Stream	S42	970339
JM 42/13	12296	Dart Stream	S42	970339
JM 42/14	12297	Dart Stream	S42	970339
JM 42/17	12298	Dart Stream	S42	970339
JM 42/18	12299	Dart Stream	S42	969340
JM 42/19	12300	Dart Stream	S42	969340
JM 43/11	12301	Muzzle Stream	S42	922299
JM 43/16	12302	Muzzle Stream	S42	923300
JM 43/17	12303	Muzzle Stream	S42	923300
JM 43/18	12304	Muzzle Stream	S42	923300
JM 43/20	12305	Muzzle Stream	S42	923300
JM 50/3	12306	Bluff Stm (upper)	S42	878275
JM 50/4	12307	Bluff Stm (upper)	S42	878275
JM 50/5	12308	Bluff Stm (upper)	S42	878275
JM 50/9	12309	Bluff Stm (upper)	S42	878275
JM 50/11	12310	Bluff Stm (upper)	S42	877276
JM 50/14	12311	Bluff Stm (upper)	S42	877277
JM 50/16	12312	Bluff Stm (upper)	S42	877276
JM 50/17	12313	Bluff Stm (upper)	S42	877277
JM 50/18	12314	Bluff Stm (upper)	S42	877277
JM 50/20	12315	Bluff Stm (upper)	S42	877279
JM 50/21	12316	Bluff Stm (upper)	S42	877279
JM 50/24	12317	Bluff Stm (lower)	S42	883245

APPENDIX V: Sample Numbers And Locations

SAMPLE NO.	UNIVERSITY OF CANTERBURY NO.	LOCATION	NZMS 1	GRID REFERENCE
JM 50/26	12318	Bluff Stm (lower)	S42	883245
JM 51/2	12319	Gentle Annie Stm	S42	827236
JM 51/3	12320	Gentle Annie Stm	S42	827236
JM 52/3	12321	Bluff River	S42	839246
JM 52/4	12322	Bluff River	S42	839246
JM 52/5	12323	Bluff River	S42	839246
JM SS 1	12324	Swale Stream	S35	130476
JM 100/1	12325	Tirohanga Stm	S36	306457
JM 100/2	12326	Tirohanga Stm	S36	306457
JM 101/1	12327	Kekerengu River	S36	267418
JM 104/1	12328	Woodside Creek	S36	334478
JM 104/5	12329	Woodside Creek	S36	335478
JM 104/13	12330	Woodside Creek	S36	299467
JM 104/14	12331	Woodside Creek	S36	299467
JM 104/15	12332	Woodside Creek	S36	299467
JM 104/16	12333	Woodside Creek	S36	299467
JM 104/17	12334	Woodside Creek	S36	299467
JM 104/18	12335	Woodside Creek	S36	299467
JM 105/3	12336	Deep Creek	S36	301502
JM 109/3	12337	Ure River	S36	293539
JM 110/3	12338	Blue Mtn Stm	S36	267552
JM 110/5	12339	Blue Mtn Stm	S36	267552
JM 111/1	12340	Ure River	S36	264544
JM 112/1	12341	Isolation Creek	S36	253535
JM 112/2	12342	Isolation Creek	S36	253531
JM 112/3	12343	Isolation Creek	S36	253528
JM 112/6	12344	Isolation Creek	S36	253522
JM 120/1	12345	Seymour Stm	S41	708125
JM 121/1	12346	Seymour Stm	S41	707125
JM 121/2	12347	Seymour Stm	S41	707125
JM 121/3	12348	Seymour Stm	S41	707125
JM 122/3	12349	Seymour Stm	S41	708125
JM 122/4	12350	Seymour Stm	S41	708125
JM 123/4	12351	The Fell	S41	697109
JM 123/6	12352	The Fell	S41	698111
JM 125/1	12353	Wallow Creek	S48	668095
JM 125/2	12354	Wallow Creek	S48	668095
JM 125/3	12355	Wallow Creek	S48	668095
JM 127/1	12356	Grass Seed Stm	S42	827188
JM 127/2	12357	Grass Seed Stm	S42	830192
JM 128/1	12358	Limestone Hill	S42	813168
JM 128/2	12359	Limestone Hill	S42	813168
JM 128/3	12360	Limestone Hill	S42	813168
JM 128/4	12361	Limestone Hill	S42	814169
JM 128/5	12362	Limestone Hill	S42	814169
JM 128/6	12363	Limestone Hill	S42	815170
JM 128/7	12364	Limestone Hill	S42	816169
JM 128/8	12365	Limestone Hill	S42	816169
JM 128/11	12366	Limestone Hill	S42	816168
JM 200/1	12367	Woodside Creek	S36	333477
JM 300/2	12368	Marfells Beach	S36	475723
JM 300/4	12369	Needles Point	S36	417546
JM 300/6	12370	Flaxbourne River	S36	436576
JM 300/8	12371	Flaxbourne River	S36	436576
JM 501/1	12372	Monkey Face	S49	702894

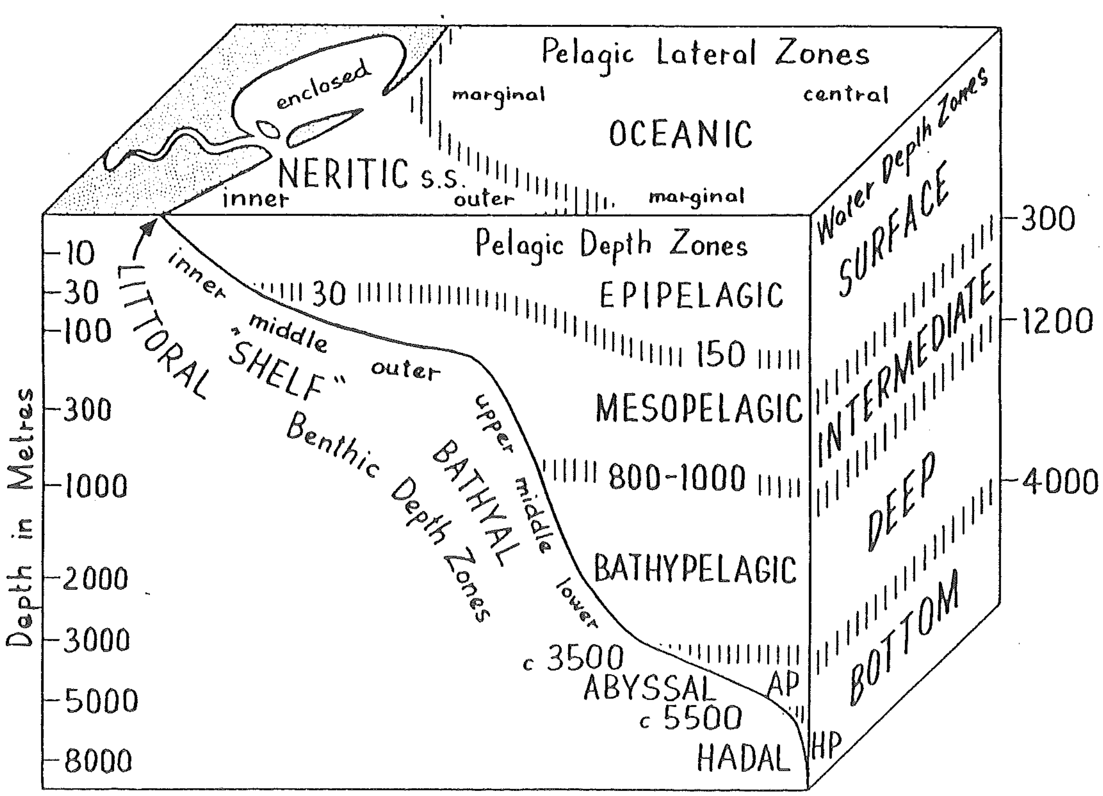
APPENDIX V: Sample Numbers And Locations

SAMPLE NO.	UNIVERSITY OF CANTERBURY NO.	LOCATION	NZMS 1	GRID REFERENCE
JM 501/2	12373	Monkey Face	S49	702894
JM 700/2	12374	Mt Alexander	S42	067145
JM 704/1	12375	Woodside Creek	S36	331469

NOTE: A CLASSIFICATION OF MARINE PALEOENVIRONMENTS

The terms "shelf" (inner, middle, outer) and "bathyal" (upper, middle, lower) are used throughout this thesis in the sense of the scheme reproduced below from Edwards (1979, p.18). These benthic depth zones are determined by paleontologists primarily on the basis of assemblages of bottom-dwelling biota and should be independent of geomorphic setting. Although it is recognized that the term "shelf" has geomorphic connotations (e.g. K.Lewis 1974), there appears to be no consensus on a replacement term. The terms "infralittoral" and "sublittoral" have previously been proposed but are not widely accepted because most marine biologists equate these with only the shallower (down to 30-50m) parts of the "shelf" depth zone. The corresponding pelagic lateral zones "neritic" (inner, outer) and "oceanic" (marginal, central) have been omitted throughout the text because the paleobathymetry has not generally been based on pelagic foraminiferal assemblages.

The following diagram, which has been taken from Edwards (1979, p.18) and describes a paleoenvironmental scheme that is generally accepted by NZ micropaleontologists, illustrates the bathymetric zonations used in this thesis.



Comment has previously been made that the uncertainties which are inherent in making these depth estimates are so great that paleontologists should instead provide paleoecological statements (Lewis 1979, p.61-62) and that paleobathymetry should be deduced from these together with other relevant factors (e.g. sedimentology). However, Edwards (1979, p.62-63) has stated that the present knowledge of the bathymetric distribution of taxa is much greater than that of their ecological distribution.

The interpretation of basin morphology during (and just prior to) deposition of the Amuri Limestone (p.224) is only partly based on the paleobathymetric determinations from foraminiferal assemblages. The schematic change in slope between shelf and bathyal depths shown in the figure above may be an artifact of modern submarine morphology and does not necessarily correspond to the Late Cretaceous - Paleogene basin morphology in east Marlborough. Other geologic factors such as lithofacies distributions, ichnoassemblages and sedimentological features were combined with benthic depth zones to achieve the basin model discussed in Chapter 7.

REFERENCES:

Edwards, A.R. 1979a: Classification of Marine Environments - a personal view. Geological Society Of New Zealand Newsletter 47: p.17-19.

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Hayward, B.W. 1986: A guide to paleoenvironmental assessment using New Zealand Cenozoic foraminiferal fauna. ew Zealand Geological Survey Report PAL 109.

Lewis, D.W. 1979: Classification of Marine Environments by Paleontologists - discussion. Geological Society Of New Zealand Newsletter 48: p.61-62.

Lewis, K.B. 1974: The continental terrace. Earth-science reviews 10: p.37-71.

NOTE: REVISED PALEOGENE TIME SCALE

(To accompany Figure 1.2)

The Paleogene Time Scale shown in Figure 1.2 (p.5 and back pocket) was compiled from the most recently available international and local data and represents a review of existing data; no new data was supplied by the author. The Time Scale essentially incorporates two data sets:

1. A revision of international Cenozoic geochronology produced by Berggren et al. (1985a,b,c).

2. The New Zealand Cenozoic micropaleontological zonation (and corresponding NZ Stages and Series) of Hoskins (1982).

At the time of its publication, the international time scale of Berggren et al. was widely regarded (e.g. Decade of North American Geology: Committee on Geochronology) as the most acceptable. Their scale correlates international calcareous plankton biostratigraphic datum events to the magnetic polarity stratigraphy of LeBrecque et al. (1977) by means of >200 first-order correlations. The absolute age of each correlation point was determined radiometrically. The absolute age (length and range) of the other international plankton zones (i.e. radiolaria, dinoflagellate) were adjusted according to their existing correlations with calcareous plankton zones.

The correlations between NZ plankton zone datums (and Stage boundaries) and their international equivalents have not been altered and are taken from Hoskins (1982). By combining these existing correlations with the revised international time scale of Berggren et al., an updated NZ time scale has been prepared in which the absolute length and boundary ages of local plankton zones and Stages conform to modern radiometric age determinations.

REFERENCES:

LaBrecque, J.L., Kent, D.V., and Cande, S.C. 1977: Revised magnetic polarity time scale for the Late Cretaceous and Cenozoic time. Geology v.5: p.330-335.